HOW IT WORKS

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HOW IT WORKS

THE MAGAZINE THAT FEEDS MINDS

DISCOVER

SCIENCE

BLOOD-SUCKING PARASITES

AMAZING CUTAWAYS

ENVIRONMENT
How bees make honey

HISTORY
Inside Florence Cathedral

TECHNOLOGY
Hi-tech mixer mechanisms

HISTORY
MODERN-DAY DINOSAURS
The surprising truth about dino descendants revealed

FUTURE COMBAT
WAR 2030

- MULTI-ROLE DRONES
- ADVANCED ARMOUR
- LASER WEAPONS

OVER **825** AMAZING FACTS & ANSWERS INSIDE

+ LEARN ABOUT

TECHNOLOGY EPIPENS **BIO-BATTERIES** SCIENCE MICROWAVES
BRAIN BANKS FARADAY CAGES ENVIRONMENT POISON CAVE
FROST QUAKES TRANSPORT HYDRAULIC BRAKES **AIRPLANE WINDOWS** SURFBOARDS HISTORY SECRET PAINTINGS
SPACE **FAST RADIO BURSTS** SPACE JUNK

FUTURE
ISSUE 109

TWO GREAT SHOWS TOURING THE COUNTRY!

'IT'S SO MUCH BETTER THAN THE BOOK!' DAVID WALLIAMS

David Walliams
GANGSTA GRANNY

★★★★

'TOTALLY GRANTASTIC!'
MAIL ON SUNDAY

David Walliams
AWFUL AUNTIE

LIVE ON STAGE!

★★★★

'ANOTHER HUGE DRAMATIC HIT!'
WHAT'S ON LIVE

See birminghamstage.com for tour dates!

ISSUE 109

WELCOME

The magazine that feeds minds!

Welcome to the latest issue of **How It Works**. This month, we take a look at the increasing importance of technology in warfare. The future of combat will likely see an increase in autonomous systems like driverless tanks and pilotless drones, as well as the development of hi-tech laser weapon systems.

While we may be engaged in conflicts on the ground, there is another growing threat above our heads. The accumulation of space junk is a recipe for disaster, and unless we come up with a solution, the satellites we rely on for GPS, weather and communications data could be at risk.

Also this issue, we delve into the weird world of parasites, discover the surprising science of the placebo effect and meet the descendants of the dinosaurs. Enjoy the issue!

Jackie **Jackie Snowden**
Editor

"We will soon see a surge in the number of soldiers who fight in wars remotely from safe locations"
Future warfare, page 12

Meet the team...

Charlie G
Production Editor
I find psychology fascinating, so learning about the impact placebos can have on our brains made for an intriguing read. How easily we can be fooled!

Baljeet
Research Editor
We humans have become pretty good at launching stuff into space, but it's also important to clean up after ourselves. Find out why on page 26.

Charlie E
Staff Writer
This month I ventured into the frightful yet fascinating world of parasites. From brain-eating bugs to rat-controlling bacteria, prepare to be revolted on page 36.

Scott
Staff Writer
Dripping in acid and filled with toxic gas, just how do the species that live in the poisonous cave of southern Mexico survive? Dare you enter on page 46?

Duncan
Senior Art Editor
When we pick up a chicken for our Sunday roast we are in fact purchasing a modern-day dinosaur! Meet the creatures that outlived the dinosaurs on page 72.

Laurie
Studio Designer
This month I was excited to read bout the prospect of eco-friendly travel. Transport yourself around the world on the record-breaking zero-fuel plane on page 52!

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+ PULL-OUT POSTER
THE BATTLE OF BRITAIN
PAGES 50-51

MEET THE EXPERTS...

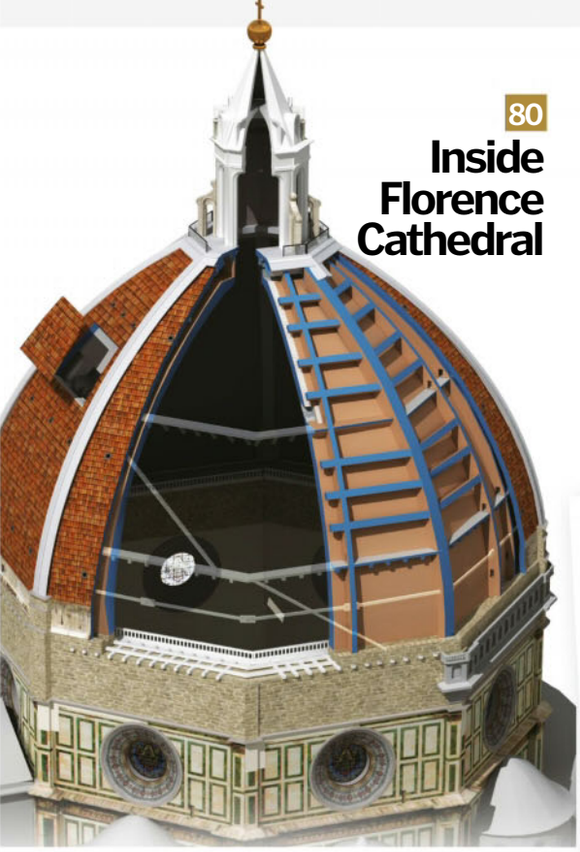
Laura Mears
This month, Laura delves into the fascinating science behind the placebo effect. Find out how our responses to sugar pills and saline injections can be used to help us develop new drugs.

Jonny O'Callaghan
In this issue, Jonny tackles the growing problem of space junk. Could we be heading for a *Gravity*-like catastrophe if we don't start cleaning up our orbit?

James Horton
War: what is it good for? Arguably, technological advancements. James reveals the next-gen defence systems that will transform warfare, from autonomous drones to laser weaponry.

Tim Williamson
In the history section, Tim takes us on a tour of Florence Cathedral, including an in-depth look inside Brunelleschi's iconic dome. Could the mystery of its construction finally be solved? Find out on page 80.

Jodie Tyley
Jodie reveals the long-lost art of fore-edge paintings on page 82. We'll all be checking old books for these hidden artworks from now on! She also explains how Marc Isambard Brunel pioneered mass production.



REGULARS

Zhong Zhong and Hua Hua are currently being bottle fed and growing normally

Two of a kind

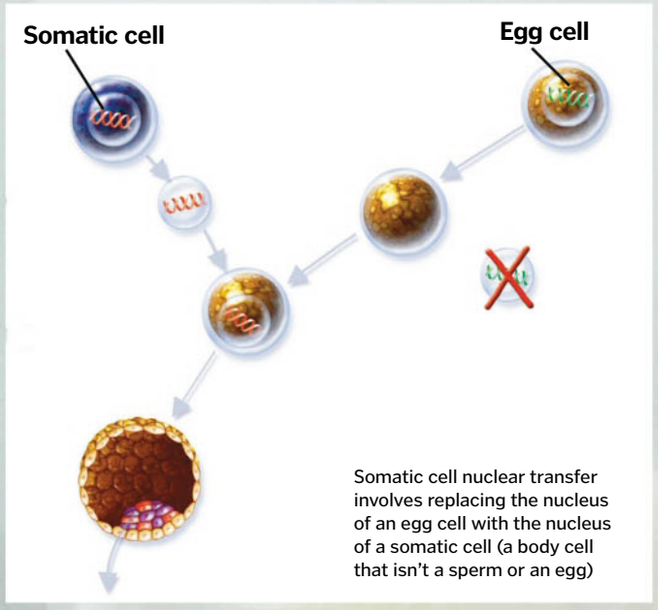
Researchers in China have successfully created the first primate clones

In a world first, scientists at the Chinese Academy of Sciences Institute of Neuroscience in Shanghai have created a pair of cloned monkeys. Born at the institute, Zhong Zhong and Hua Hua are two genetically identical long-tailed macaques. According to the scientists' findings, published in the scientific journal *Cell*, the two monkeys were cloned using a method known as somatic cell nuclear transfer.

This involves removing the nucleus of an egg cell, transferring the nucleus of a donor somatic cell (body cell) into the egg cell and implanting this into a surrogate. The nucleus of the cell holds all the genetic information needed to form an organism. This method had not previously been successful in monkey cell nuclei. So, the team used non-genetic modulators to halt the activation and deactivation of genes that prevent the embryos from dividing and developing.

This breakthrough could have wide-ranging applications, as explained by Qiang Sun, senior author of the report. "You can produce cloned monkeys with the same genetic background except the gene you manipulated. This will generate real models, not just for genetically based brain diseases, but also cancer, immune or metabolic disorders and allow us to test the efficacy of the drugs for these conditions before clinical use."

"The monkeys are two genetically identical macaques"



Somatic cell nuclear transfer involves replacing the nucleus of an egg cell with the nucleus of a somatic cell (a body cell that isn't a sperm or an egg)

Following Dolly

Zhong Zhong and Hua Hua aren't the first mammals to be have been cloned. Born in 1996, at the Roslin Institute in Scotland, Dolly the sheep was genetically cloned using the same techniques as the two macaques. Initially Dolly was cloned to explore medicine production in milk. She was bred with a Welsh mountain ram named David, producing a total of six lambs. Sadly, by 2001 Dolly was suffering with arthritis, and in 2003 a virus-induced lung tumour meant she was humanely put to sleep. Since her passing Dolly's body has been exhibited at the National Museum of Scotland in Edinburgh.

A NEW EXOPLANET HUNTER

The latest telescopes have made their first observations in the hunt for habitable exoplanets

The latest addition to the ESO's La Silla observatory in northern Chile, last month the Exoplanets in Transits and their Atmospheres (ExTrA) telescopes made their first successful observations. ExTrA will be focusing on the smaller stars known as M dwarfs, which are believed to be the most common kind in the universe, accounting for as much as 70 per cent of the stars in our galaxy. It is thought that these star systems could host Earth-sized planets.

Three 0.6-metre telescopes make up ExTrA, which will be used to search for signs of potential habitable planets in star systems. Each telescope monitors the light received from these stars, identifying fluctuations in brightness that could suggest the presence of orbiting planets. The detected light is then compared with that of four other reference stars. The data is then fed through optical fibres into a near-infrared spectrograph before being sent into one multi-object spectrograph, known as a differential photometry approach. This is different from the transit method (typically used by space-based telescopes) and will use reference stars of different colours to help combat the interference from the Earth's atmosphere, thereby dramatically improving precision.

It is hoped that any candidate exoplanets identified by ExTrA could be studied in further detail by the next generation of telescopes, such as the ESO's Extremely Large Telescope, which is currently under construction. These telescopes could soon be used to analyse the properties and compositions of exoplanets, comparing their similarities to Earth and their potential ability to support life as we know it.

Team member Jose-Manuel Almenara explained the exciting potential of these space-scanning giants. "With ExTrA, we can also address some fundamental questions about planets in our galaxy. We hope to explore how common these planets are, the behaviour of multi-planet systems and the sorts of environments that lead to their formation."

Ground-based telescopes require optimal atmospheric conditions to hunt for exoplanets

New iron giant exoplanet discovered

A new exoplanet approximately five times the mass of Earth has been found by NASA's Kepler telescope. Named K2-141 b, this exoplanet is denser than Earth due to its incredibly large iron core, and it takes just six hours to orbit its orange-red K dwarf parent star. The planet also has a Neptune-sized companion that takes only slightly longer to orbit its sun in eight days. Known as a super-Earth, the origins of the planet are not fully understood. Let's wait and see what the ExTrA telescope will discover.

K2-141 b is known as an ultra-short period planet because it orbits its parent star so rapidly

NEWS BY NUMBERS

11 billion

pieces of plastic are polluting Asia-Pacific corals

10%

of hydrogen on Mars is lost due to dust storms

400 million

the number of years ago the first insect wings evolved, as revealed in a new study

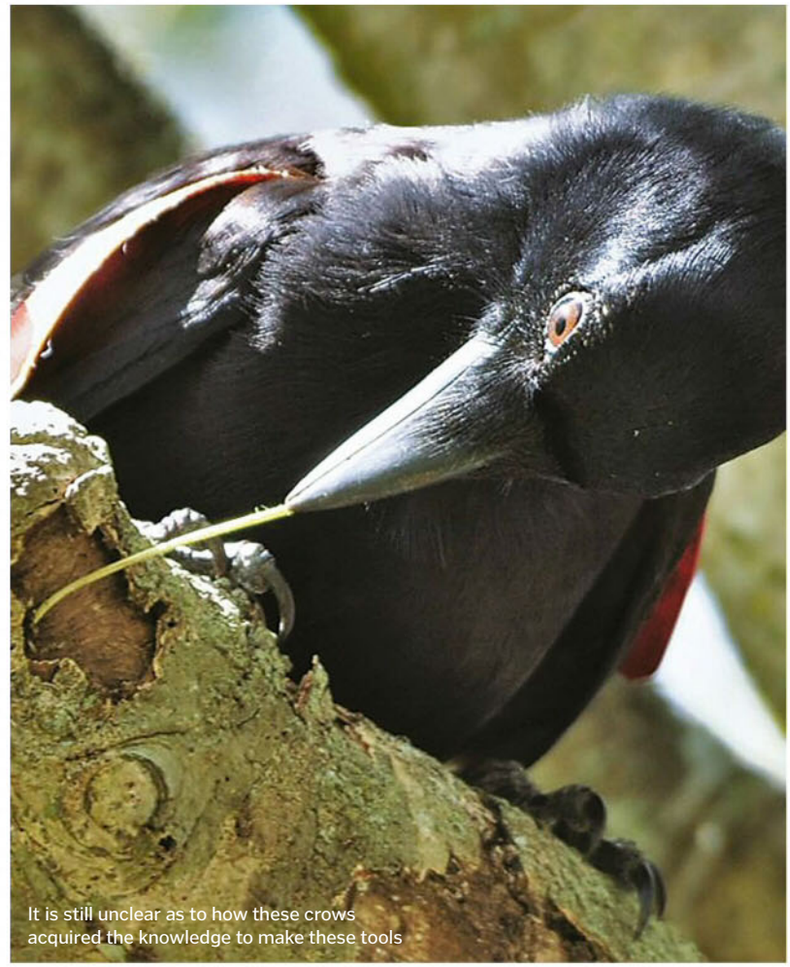
18 minutes

The length of time that a naked mole rat can survive without any oxygen

Crafty crows make fast food tools

Study reveals a crow species using tools for a quicker meal

A study conducted by the universities of St Andrews and Edinburgh has revealed another animal group capable of using tools to complete tasks. As the only non-human animal known to use a hooked tool, New Caledonian crows have their own method of getting fast food. It has been observed that these birds create makeshift hooks – typically from sticks – to hunt for insects often buried in bark in the wild. Findings published in the journal *Nature Ecology & Evolution* have revealed that when given the option between hooked and non-hooked tools, the crows opted for a hooked tool, which is two to ten times more efficient than its un-hooked counterpart.



It is still unclear as to how these crows acquired the knowledge to make these tools

People working in the STEM community created the images for the exhibition

The world's first invisible photography exhibition

The miniaturised pictures that are as wide as a human hair

The unique exhibition, *Dotography: The World's First Invisible Photography Exhibition,* in Birmingham, UK, combines the wonder of science and art by creating photographs that are invisible to the naked eye.

Visitors were given a high-spec handheld microscope that attached to the back of their smartphone. When approaching artwork their camera would reveal the miniature image on display. All the 22 pictures on display relate to science, technology, engineering and maths, and included iconic scientific figures such as Marie Curie, Albert Einstein, J Robert Oppenheimer and Neil Armstrong.

Ochre was a prehistoric pigment used by our ancient ancestors to colour animal skins and create cave art

An ancient crayon has been found

Discovered near an historic lake, this ochre crayon reveals a colourful past

Believed to date back 10,000 years, an ancient ochre crayon and an ochre pebble have been found by archaeologists near a lake in Scarborough, North Yorkshire. Ochre is a natural clay mineral that was used by prehistoric hunter-gatherers.

"The pebble and crayon were located in an area already rich in art. It is possible there could have been an artistic use for these objects, perhaps for colouring animal skins or for use in decorative artwork," said lead author Dr Andy Needham in a statement.

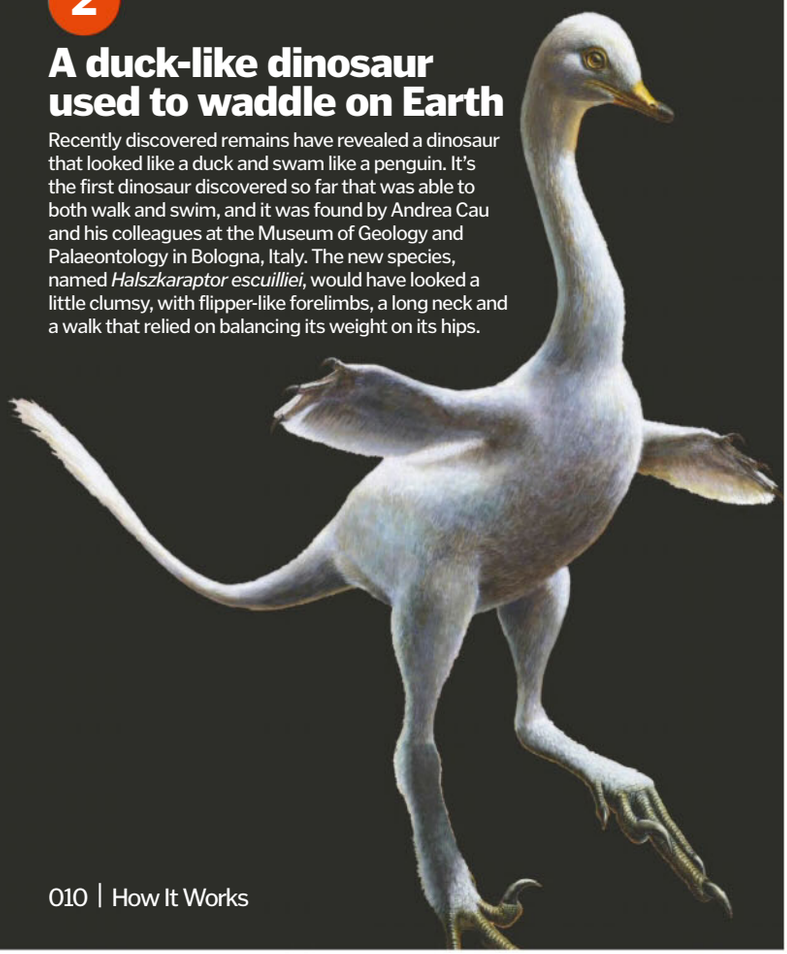
10 COOL THINGS WE LEARNED THIS MONTH

1 Scientists have linked extreme weather to human activity

Studies published in the December 2017 issue of the *Bulletin of the American Meteorological Society* (*BAMS*) have shown that certain extreme weather events in 2016 could not have been caused by natural climate variations alone. The events listed included the deadly heat wave that swept across Asia, the global increase in temperature (resulting in the hottest year on record) and areas of unusually high ocean temperatures that caused mass die-offs. The reports link these events to the human influence on the global climate, such as the atmospheric warming from fossil fuel use.

2 A duck-like dinosaur used to waddle on Earth

Recently discovered remains have revealed a dinosaur that looked like a duck and swam like a penguin. It's the first dinosaur discovered so far that was able to both walk and swim, and it was found by Andrea Cau and his colleagues at the Museum of Geology and Palaeontology in Bologna, Italy. The new species, named *Halszkaraptor escuilliei*, would have looked a little clumsy, with flipper-like forelimbs, a long neck and a walk that relied on balancing its weight on its hips.



3 Scientists can block the siren call of aggressive cancers

Aggressive cancers like glioblastoma and metastatic breast cancer use a 'siren call' that signals to the bone marrow to send over the resources needed for the tumours to thrive. A recent breakthrough has started testing a new treatment that aims to block the production of this chemical messenger (called 20-HETE) in order to slow or prevent the growth and spread of tumours.

4 Two famous Egyptian mummies had different daddies

DNA analysis on a pair of ancient Egyptian mummies, known as the Two Brothers, has revealed that they were actually half-brothers. The priests Khnum-nakht and Nakht-ankh were discovered in Egypt in 1907. They had originally been assumed to be brothers when they were discovered together, and inscriptions on their sarcophagi implied they were both the sons of a governor. Each one also lists the same name for their mother Khnum-aa. The study confirmed their true relationship by using DNA taken from inside the teeth of their remains.

5

Nanotechnology could be used against malaria

Pharmacologist Professor Andrew Owen and materials chemist Professor Steve Rannard want to use nanotechnology to improve how an existing antimalarial drug is administered to make the treatment last longer. Nanoparticles thousands of times smaller than the width of a human hair are injected into muscle, where they can release the drug into the bloodstream slowly over an extended period of time.

6

Stroke survivors may benefit from a special diet

The MIND (Mediterranean-DASH Diet Intervention for Neurodegenerative Delay) diet may reduce the risk of cardiovascular conditions such as high blood pressure, heart attack and stroke. Scientists from Rush University Medical Center in Chicago, US, have found that the diet promotes brain health as it includes plenty of vegetables, berries, fish, and olive oil, and it has the potential to slow cognitive decline after a stroke.

7

Mathematicians can predict tsunami impacts

Acoustic gravity waves are generated in the deep ocean just after tsunami-triggering events, such as underwater earthquakes. Researchers hope to use the fast-moving underwater sound bursts as a real-time early warning system and to help predict the size and force of the waves.

8

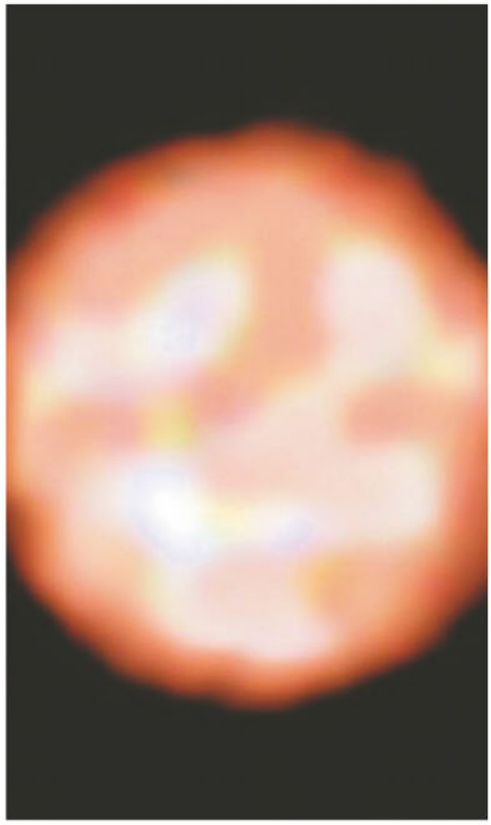
Naked mole rats don't really age

You would assume that the older an animal gets the more likely it is to die. A logical assumption, but one that the naked mole rat has proven wrong; this superhero species defies the laws of biology. The chances of them dying remains at about one in 10,000 throughout their life, from birth through to sexual maturation and beyond.

9

Astronomers directly observed a giant star's surface

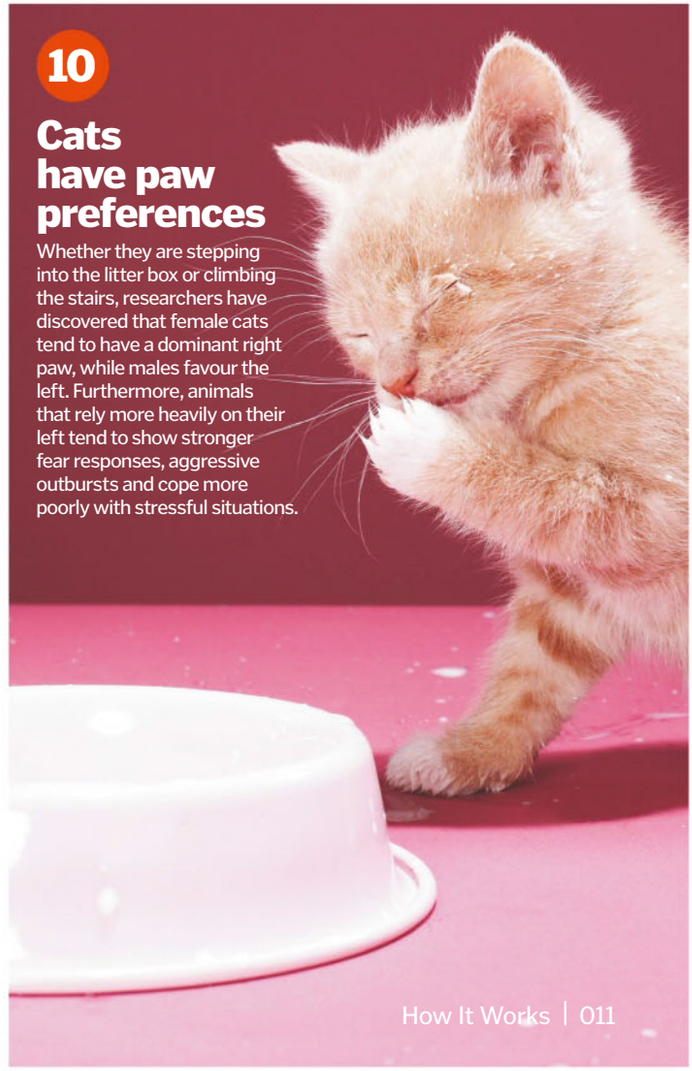
An international team have taken images of a giant star outside our Solar System in greater detail than has ever been achieved before. The result has revealed that Pi1 Gruis is almost completely circular, with a complex convective pattern and dust-free atmosphere.



10

Cats have paw preferences

Whether they are stepping into the litter box or climbing the stairs, researchers have discovered that female cats tend to have a dominant right paw, while males favour the left. Furthermore, animals that rely more heavily on their left tend to show stronger fear responses, aggressive outbursts and cope more poorly with stressful situations.



FUTURE COMBAT
WAR 2030

The transformative technologies that will redefine the battleground

For a soldier fighting around a century ago, today's weaponry and assistive technology would, for the most part, appear completely alien. Long gone are the cavalry charges, bayonets and almost exclusively ground-based fighting. Now our ground troops are protected by bulletproof Kevlar while drones and fighter jets patrol above their heads. We may believe that we've reached the pinnacle of combat technology, but in another century the battle landscape will have taken another huge evolutionary leap forward.

We stand on the cusp of this new technological era; remote-controlled aircraft surf the skies and revolutionary prototypes are constantly being designed and tested in the field. Unmanned aerial vehicles, commonly known as UAVs, are of particular interest to government-funded research teams. One branch of the Pentagon recently unveiled a swarm of drones that could communicate with each other and provide surveillance of a wide area. They may soon be employed to jam enemy communications.

> *"We stand on the cusp of this new technological era"*

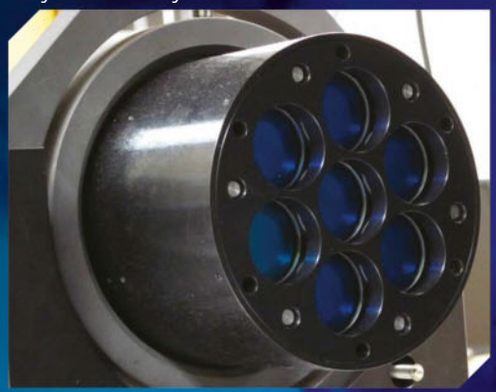
Infantry units will also benefit from the ascendancy of technology, as engineered exoskeletons will upgrade both their endurance and protection. Lower-limb exoskeletons will be affixed to the flanks of a soldier's legs and their spine via straps – such as in University of California, Berkeley's BLEEX design – enabling them to carry heavier payloads and wear more armour. There will also be 'soft' exoskeleton variants such as DARPA's Warrior Web concept: a lightweight under-suit – visually similar to a diver's wetsuit – designed to protect and support injury-prone soft tissues and help mitigate against muscular fatigue.

Perhaps the most impactful of all incoming technologies, however, is the rise of automation. With our ever-growing ability to write intuitive

algorithms and construct sophisticated sensors, it is becoming possible to remove humans from a weapon's control and decision-making process entirely. Fully automated defence weapons are already in widespread use in the form of the Phalanx system, which is a combination of sensors, software and a Gatling gun found on many naval warships. When the system senses an incoming missile, it will automatically locate, aim at and destroy the threat much faster than any human controller would be capable of doing.

However, aside from dealing with clear threats, such as incoming missiles, it will be much more difficult (and morally questionable) to give an autonomous system complete control. As a result, governments and private companies are hard at work designing and implementing near-autonomous war machines of all kinds, from tanks to drones, all of which will require human input for the use of aggressive force.

This means that we will soon see a surge in the number of soldiers who fight in the theatres of war from safe locations thousands of miles from the action on the front line. Tanks will patrol the ground and drones the air, able to autonomously navigate and take defensive actions in real-time by avoiding the command lag from a human controller positioned miles away. But when it comes to utilising weaponry, a soldier will be able to process the relayed information and dictate the required response. The US Navy, in particular, is so confident in the rise of autonomous war vehicles that the nation's defence secretary has claimed that their latest batch of manned strike jets will likely be the last they will ever buy.



Excalibur consists of optical phased array technologies, which create lightweight and compact laser weapons

Laser lenses

Monitoring the enemy is an integral task for any military force, and with the increase in ground-to-air missile systems it has become more difficult yet more essential than ever before. Fortunately, BAE Systems' Laser Developed Atmospheric Lens concept could hold the solution to this problem by providing detailed landscape monitoring at a safe distance with the help of lasers.

Once at high altitude, an aircraft will utilise laser beams to temporarily excite or ionise a small region of the atmosphere. This will allow for light to become distorted via refraction, reflection or diffraction as it moves through the area, essentially converting the region of atmosphere into a magnifying lens. By combining this approach with advanced sensors, soldiers will able to monitor operations on the ground below in detail. And the advantages of this tech don't stop there, as the Atmospheric Lens can also be used as a laser deflection shield to block incoming counter-attacks from enemy beams.

LASER WEAPONS

A technology inspired by fiction that's destined to become a revolutionary weapon of war

When H G Wells' Martian tripods first appeared in *The War of the Worlds* novel, they rained down terror on their human victims with their 'heat-rays', which fired invisible beams of energy that set ablaze everything they touched. People perished and the Martians conquered, bringing humanity's reign as the dominant species to an end. This pioneering piece of science-fiction, first published in 1898, set the world's imagination afire as people pondered whether aliens could come from Mars to harm us. But perhaps no one considered that just over a century later we would have created the heat-ray by a different name: the laser beam.

However, unlike the heat-ray, our lasers need not be limited to simply over-heating targets – although that is one planned use. Instead, these beams of energy will be utilised in many areas of combat, from communications to target tracking to target destruction. This diverse array of potential applications stems from the matter that comprises the beams – electromagnetic radiation. Different wavelengths, spanning across the electromagnetic spectrum, can yield their own advantages. Blue-green light in the visible region, for example, can transmit data between underwater vessels with far more accuracy and speed than the radio waves commonly used by submersibles today. In terms of removing an opponent from battle, laser beams composed of infrared radiation can cripple sensors or generate heat to devastating effect.

Scientists and engineers have made enormous progress since the laser was first demonstrated in 1960. In 2014, the USS Ponce was equipped with a multi-functional Laser Weapon System for trial testing that was able to beam drones out of the sky, and many other countries and companies are hot on the US's heels in terms of creating even better laser tech. The race for battlefield dominance is on, and the laser will likely soon be a common sight on the ground, underwater, in the air and in orbit.

Enemy activities could be monitored closely by lasers that temporarily convert the atmosphere into a magnifying lens

Beams from above

Despite the mammoth advances that have been made in laser technology so far, there are still considerable hurdles to overcome. Primarily, these include their heavy weight, the excess heat that's generated as they're used and the substantial power requirements needed to fire them. These may not be major issues on large navy vessels, but they present significant hindrances to aircraft-mounted laser weapons.

Fortunately for laser enthusiasts, Lockheed Martin has accepted the challenge and is developing its SHiELD (Self-protect High Energy Laser Demonstrator) programme with the eventual goal of providing aircraft with enemy-disabling laser turrets. The team of researchers will construct a beam control system for accurate target acquisition, a mounted pod that will both power and cool the laser beam, and a high-energy beam itself. Trials are currently planned to commence in 2021, and if successful, this weapon could be set to irreversibly alter warfare shortly after.

Lockheed Martin is designing a lighter, cooler and less energy-expensive laser for fighter jets

"Laser will be utilised in many areas, from communications to target destruction"

Neutralisation
Missiles at high altitudes can be identified, monitored and destroyed at considerable distances by powerful laser beams.

Counter-offensive
Laser technology will be able to defend against other laser-based weapons, dazzling their sensors and disrupting their use.

Target locked
Laser tracking systems are already proving to be optimal choices for monitoring enemy drones and other aircraft.

Threat removal
Concentrated infrared lasers can cause a significant build-up of heat to disable or even obliterate targets.

Commanders may soon be able to use augmented reality to construct a virtual command base from anywhere in the world

It may be easy to think of future military technologies as simply new ways to wreak havoc, but multiple pioneering research avenues are working towards reducing the environmental impact of warfare. Lasers, for example, have piqued the interest of those behind government-funded projects by promising an array of different military applications. Some will be used for surveillance, but others will be designed to eliminate enemy threats, and these will offer firepower in the form of beams of energy as an alternative to environmentally harmful bullets and missiles.

For ground troops, who will likely be equipped with rifles for the foreseeable future, biodegradable training bullets are currently being developed. Today's ammunition produces metal shells and lead cores as waste products that can contaminate soil and groundwater. One innovative solution involves placing bioengineered seeds inside the bullet cores. These will have extended germination periods that should coincide with the time it takes for the bullet to degrade. This way, when the seeds are ready to sprout, they'll be safely nestled inside nurturing soil. It may seem oxymoronic that militaries are conscious of reducing their impact on our planet, but nonetheless these eco-friendly measures are a welcome change from the conventional, polluting by-products of battle.

"Ironclads will form the eyes and ears of the autonomous army"

Civilians will also inevitably benefit from the technologies that are born on the battlefield, as they have done on numerous occasions throughout history. Radar is a famous example of a technology developed during wartime that became invaluable to civilian life not long after. The case may even be made for nuclear fission as well, given that nuclear power offers cleaner energy production than burning fossil fuels.

Eventually, these new technologies will filter into our lives, and we may imagine that drone swarms will scan sites following natural disasters and identify victims in need of aid; exoskeletons will be able to support those who are physically handicapped or require rehabilitation; and automated passenger jets will be able to react accordingly at the slightest change in environmental conditions, ensuring a much safer flight. The technological agents of war may be almost unrecognisable in the decades to come, but thanks to these innovative strides, so too may our technology at home.

BROADSWORD SPINE

The future of warfare, as shown within this feature, will be dominated by autonomous vehicles coordinating with human soldiers. Electronic devices will facilitate the exchange of information between man and machine and so will continue to grow in both prevalence and importance. Ensuring that these remain connected and powered, then, becomes equally essential, and will be achieved with the help of the Broadsword Spine.

This cable-free vest will contain a conductive e-textile loom that will connect power supply and data between devices. A soldier's devices can then be attached to the gear in various locations for their convenience. The weave will offer a more flexible, robust and lighter alternative to other power supply garments.

This strive in technology will help to increase synergy between foot soldiers and the ever-growing number of autonomous robots around them, which will provide an imperative advantage in future conflicts.

A wearable electronic supply

Revealing the invisible power and data network woven inside the Broadsword Spine

Control hub
The centrepiece of the tech is the power and data manager (positioned on the back), which ensures both are distributed across the network.

E-textile loom
Conductive yarns are used in place of traditional wires and cables, providing greater flexibility to the material.

Simple connectivity
USB ports adorn the gear at multiple locations, offering easy access points for many pieces of electronic equipment.

THE IRONCLAD LEGION

If the whole is greater than the sum of its parts, then no technology better exemplifies this than BAE Systems' Ironclad machines. Designed to operate and share information with other units autonomously, these versatile units will coordinate to form 'battle groups' that will provide a protective barrier for troops on the front line.

With their rubber asymmetric tracks, Ironclads will be able to navigate tight alleyways as part of urban warfare and climb steep inclines when patrolling rugged terrain. Their armoured hull will protect from both blasts and small arms fire, and their batteries will permit a respectable range of 50 kilometres. Multiple, easily exchangeable pieces of equipment will be affixed to their vehicular base, allowing Ironclad squads to be situationally altered.

The Ironclads will be used as enforcers, defenders, rescuers and scouts. But perhaps most importantly they will form the eyes and ears of the autonomous army, sharing their acquired data with soldiers and other autonomous vehicles alike, a vital asset in the chaos and confusion of war.

Area denial
This variant will detect enemies with imaging and audio sensors before engaging them at range with its remote weapon station.

Autonomous sensor
Imagery and audio will be broadcast live to infantry troops, allowing the Ironclad to act as a scout in treacherous environments.

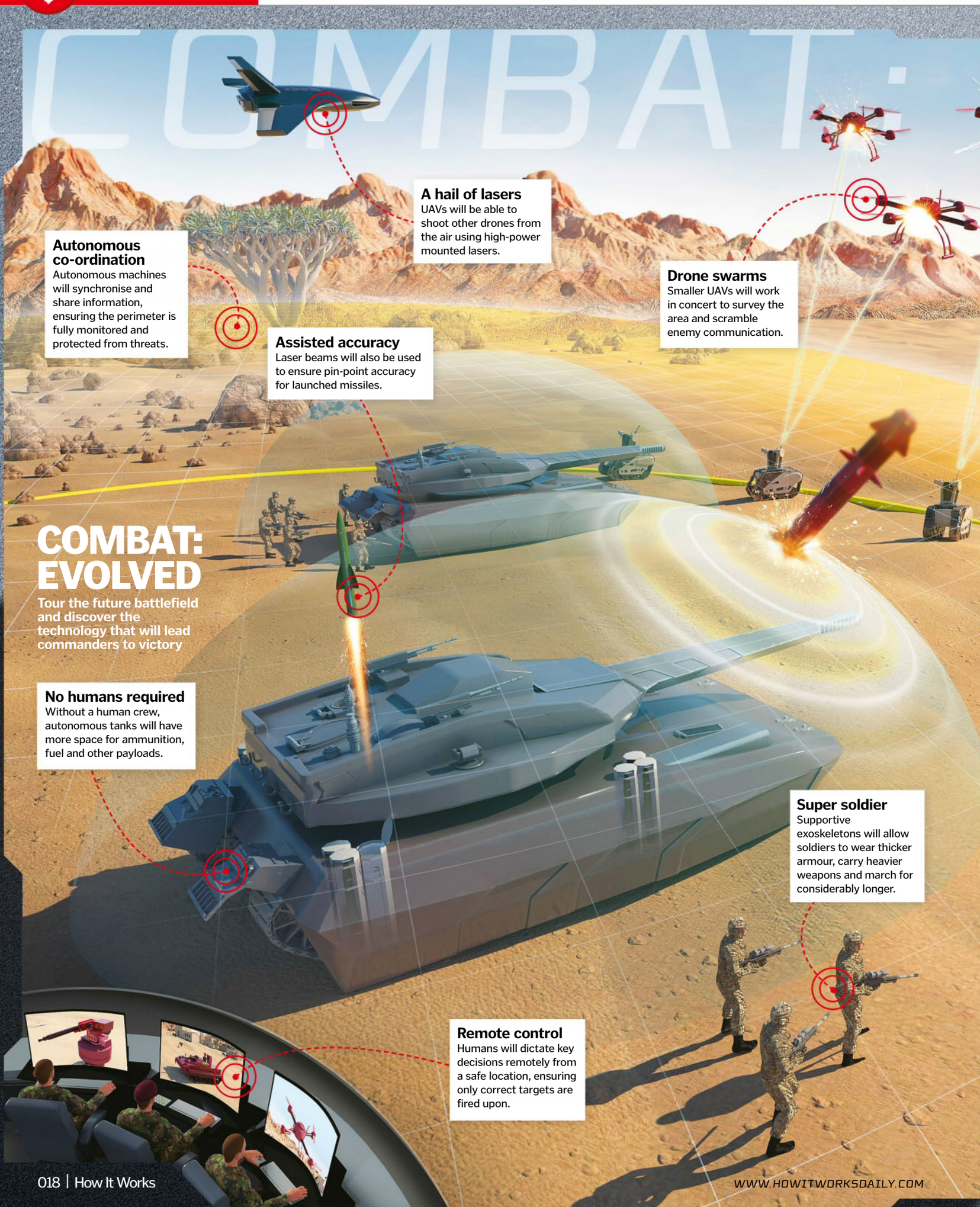
Explosive ordnance disposal
A mobile arm will be used to remove hidden improvised explosive devices before infantry troops reach the area.

Medivac
A specialised stretcher will be affixed to two vehicle bases for the safe evacuation of soldiers injured during a conflict.

The ViSAR programme is working to develop extremely high frequency targeting sensors that can 'see' through clouds

BAE Systems envision replacing all aircraft controls aside from the control stick with virtual variants

The Warrior Web under-suit will reduce muscle injury and fatigue, helping soldiers remain active for longer


COMBAT:
A hail of lasers
UAVs will be able to shoot other drones from the air using high-power mounted lasers.
Autonomous co-ordination
Autonomous machines will synchronise and share information, ensuring the perimeter is fully monitored and protected from threats.
Drone swarms
Smaller UAVs will work in concert to survey the area and scramble enemy communication.
Assisted accuracy
Laser beams will also be used to ensure pin-point accuracy for launched missiles.
COMBAT: EVOLVED
Tour the future battlefield and discover the technology that will lead commanders to victory
No humans required
Without a human crew, autonomous tanks will have more space for ammunition, fuel and other payloads.
Super soldier
Supportive exoskeletons will allow soldiers to wear thicker armour, carry heavier weapons and march for considerably longer.
Remote control
Humans will dictate key decisions remotely from a safe location, ensuring only correct targets are fired upon.

Reactor-grown tech
Bespoke UAVs will be grown in chemical reactors and become battle ready in just a few weeks after inception.

Ironclad
The Ironclads will operate autonomously and work together as a battle group, forming a formidable defensive vanguard.

Future drones may be able to alternate between rotary-wing flight for vertical take-offs and fixed-wing flight for greater speed

Growing drones through chemistry

Battles, and wars, are often won by the side that's better equipped to deal with the task at hand, but in a large-scale conflict being fought on multiple fronts, how can one be prepared for any and all challenges? The answer may be found within a unique form of 3D printing that uses chemical reagents as 'inks' to build structures, such as UAVs, from the bottom-up. These are envisioned by BAE Systems and their partners at Glasgow University and Cronin Group PLC to be able to grow drones in a matter of weeks, rather than the years required currently.

With this swift construction period, bespoke UAVs could be built specifically to achieve an immediate goal. Perhaps a secluded cohort of troops deep in enemy territory will soon be in need of swift air supply drops. With this technology, engineers could rapidly assemble streamlined drones with mechanised payload drop hatches to ensure that their troops receive what they need exactly when they need it.

Drones may soon be 'grown' in chemical reactors in a matter of weeks

Stand mixers

Discover how this useful kitchen gadget transformed the way we bake

Baking can be hard work, particularly when you have to mix all of the ingredients together by hand. If you're planning to make a lot of cakes, cookies and other tasty treats at home, then a stand mixer could be a worthwhile investment, as it will certainly save your mixing arm from getting tired.

Stand mixers differ from food processors because they are designed to combine ingredients using a beater rather than chop them using a blade, which makes them ideal for baking. They work in much the same way as their handheld electric counterparts, with a motor that drives a set of gears causing a mixing attachment to rotate. When placed in your bowl of ingredients, the spinning attachment combines everything together to create a dough, batter or any other type of mix. The benefit of a stand mixer is that you don't need to hold it while it works, freeing up your hands to get on with other tasks. They also allow you to mix together your ingredients at a choice of different consistent speeds, helping to make sure your bakes are perfect every time.

The very first food mixers, called egg beaters, were patented in 1884 and were operated by hand. To mix your ingredients you had to crank a wheel that would then turn a set of gears and rotate the beaters. Eventually, an electric version was introduced, and then in 1908 the stand mixer was invented.

Herbert Johnson, an engineer at the Hobart Manufacturing Company, came up with the idea after watching an exhausted baker trying to mix some bread dough with a spoon. It wasn't long before his new mixer had revolutionised the baking industry, and in 1919 a domestic version was created for home cooks too.

Stand mixers take the hard work out of baking

Marvellous mechanised mixing

Discover how the different parts of a stand mixer work to make life easier

Gears
A series of gears work together to convert the horizontal spinning of the motor into the vertical spinning and rotary motion of the beater.

Beater shaft
This vertically spinning shaft can be fitted with a variety of attachments that mix the contents of the bowl.

Hook
The hook can be used to mix dough, ensuring the gluten develops to create fluffy, chewy bread.

Mixing bowl
The bowl has a large dimple on the bottom to stop ingredients getting stuck there unmixed.

Motor
Here electrical energy is converted into mechanical energy, producing the spinning action of the gears.

Speed sensor
This sensor monitors the motor's spinning speed and transmits information to and from the mixer's control panel.

Spiral mixers are a type of stand mixer used for making bread

Spring-loaded lever
This lever locks the bowl into the correct position so that the beater can do its job without hitting the sides of the bowl.

"The benefit of a stand mixer is that you don't need to hold it while it works"

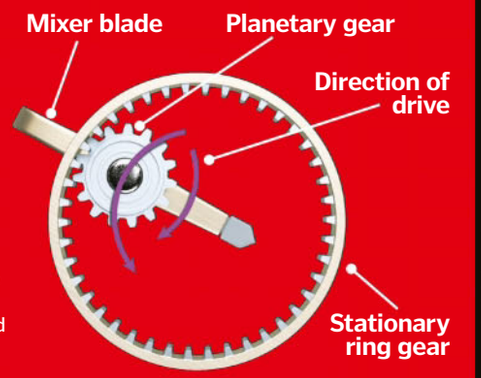
Flat beater
This attachment can be used for cakes, cookies, mashed potato and many other mixtures.

Flex-edge beater
This attachment's flex-edge will help to scrape a mixture off the sides of the bowl.

Wire whisk
The whisk attachment whips air into liquid mixtures to create meringues and sauces.

Planetary mixers vs spiral mixers

There are in fact two different types of stand mixer: planetary mixers and spiral mixers. Planetary mixers, like the one featured on this page, have a fixed bowl and a rotating attachment. As the attachment is interchangeable, this type of mixer is very versatile as it can create a wide range of mixtures. Spiral mixers, on the other hand, have a rotating bowl and a fixed, static attachment, typically a hook. They are ideal for making bread because they create less friction than a planetary mixer. This ensures that the dough does not increase in temperature while being mixed, allowing it to rise properly when baking.



Planetary mixers use a series of gears to drive the rotating attachment

The EpiPen

How these pocket-sized pens can save a life

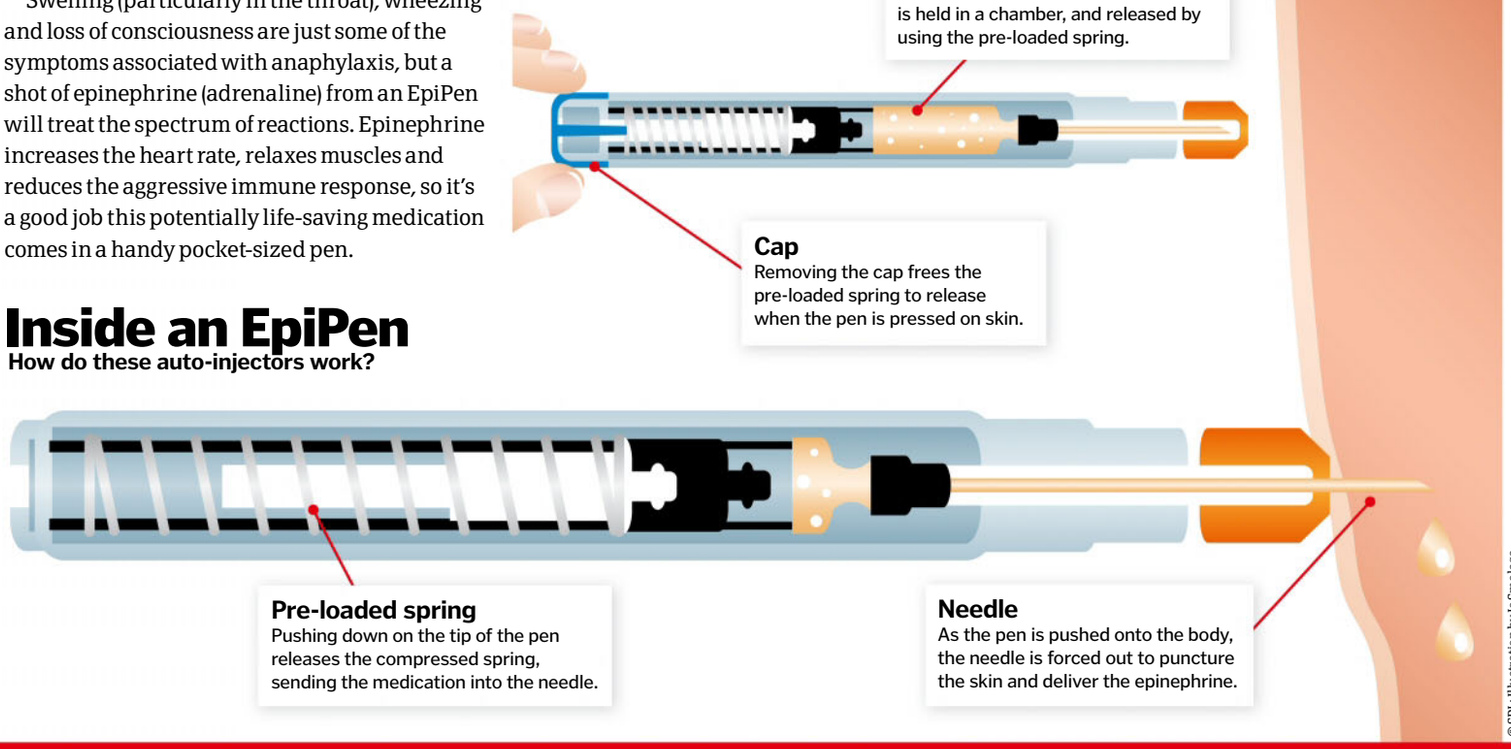
For those with severe allergies, an EpiPen should always be close to hand in case of an anaphylactic shock. Caused by an intense immune response to allergens such as a bee sting or peanuts, anaphylaxis occurs quickly after contact with an allergen. Inflammatory molecules called mediators are released by the immune system en masse, leading to the symptoms of an allergic reaction.

Swelling (particularly in the throat), wheezing and loss of consciousness are just some of the symptoms associated with anaphylaxis, but a shot of epinephrine (adrenaline) from an EpiPen will treat the spectrum of reactions. Epinephrine increases the heart rate, relaxes muscles and reduces the aggressive immune response, so it's a good job this potentially life-saving medication comes in a handy pocket-sized pen.

The first modern EpiPen was invented in the mid-1970s

Inside an EpiPen

How do these auto-injectors work?



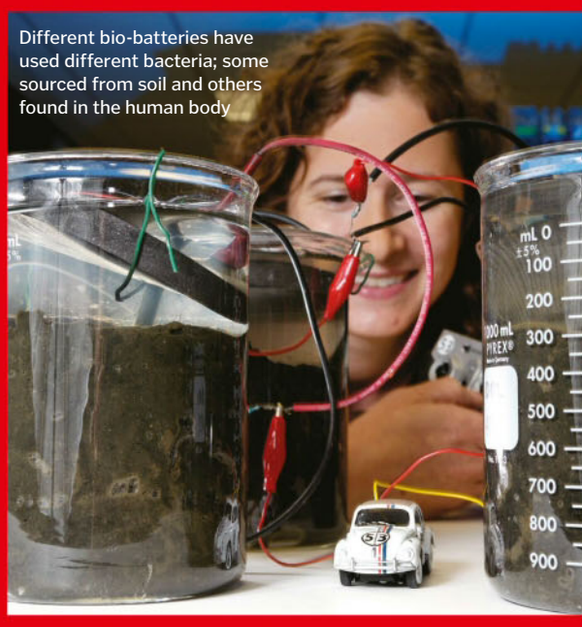
Microbial fuel cells

The bio-batteries using bacteria and sugar to produce power

The battery industry is worth billions, but the benefits of producing these miniature marvels are not without their drawbacks: scientists are becoming increasingly concerned by the environmental impact of such huge-scale production. Finding a cleaner way to power the world is becoming ever-more important, and this is where bio-batteries come in.

To create them, bacteria such as rhodoferax are placed in a sugary solution along with a graphite electrode. As the bacteria feed on the sugars their metabolism breaks the molecules down, releasing electrons. These electrons are attracted to a positively charged electrode, thereby producing a current. In one study, researchers found that 80 per cent of the electrons in sugar molecules were converted into electricity. It's been suggested the energy produced by the bacteria from a cup of sugar could power a 60-watt light bulb for 17 hours.

Ultimately, it is hoped these batteries can be used as an alternative power source. One ingenious idea is to use them to power cardiac pacemakers, since there is a constant supply of sugar flowing through your bloodstream, which a bio-battery could utilise.



Different bio-batteries have used different bacteria; some sourced from soil and others found in the human body

Inside the iPhone X

We take a look at what's under the glass of the latest iPhone

Apple's all-new iPhone X might be expensive, but Apple has celebrated the tenth anniversary of the iPhone by releasing one of the best smartphones available in the world today.

The edge-to-edge OLED screen offers exceptional visuals; the Face ID sensor lets you unlock your phone (and use animated emojis) just by looking at it; and the new wireless charging loop makes powering up your device as simple as placing it down on a mat.

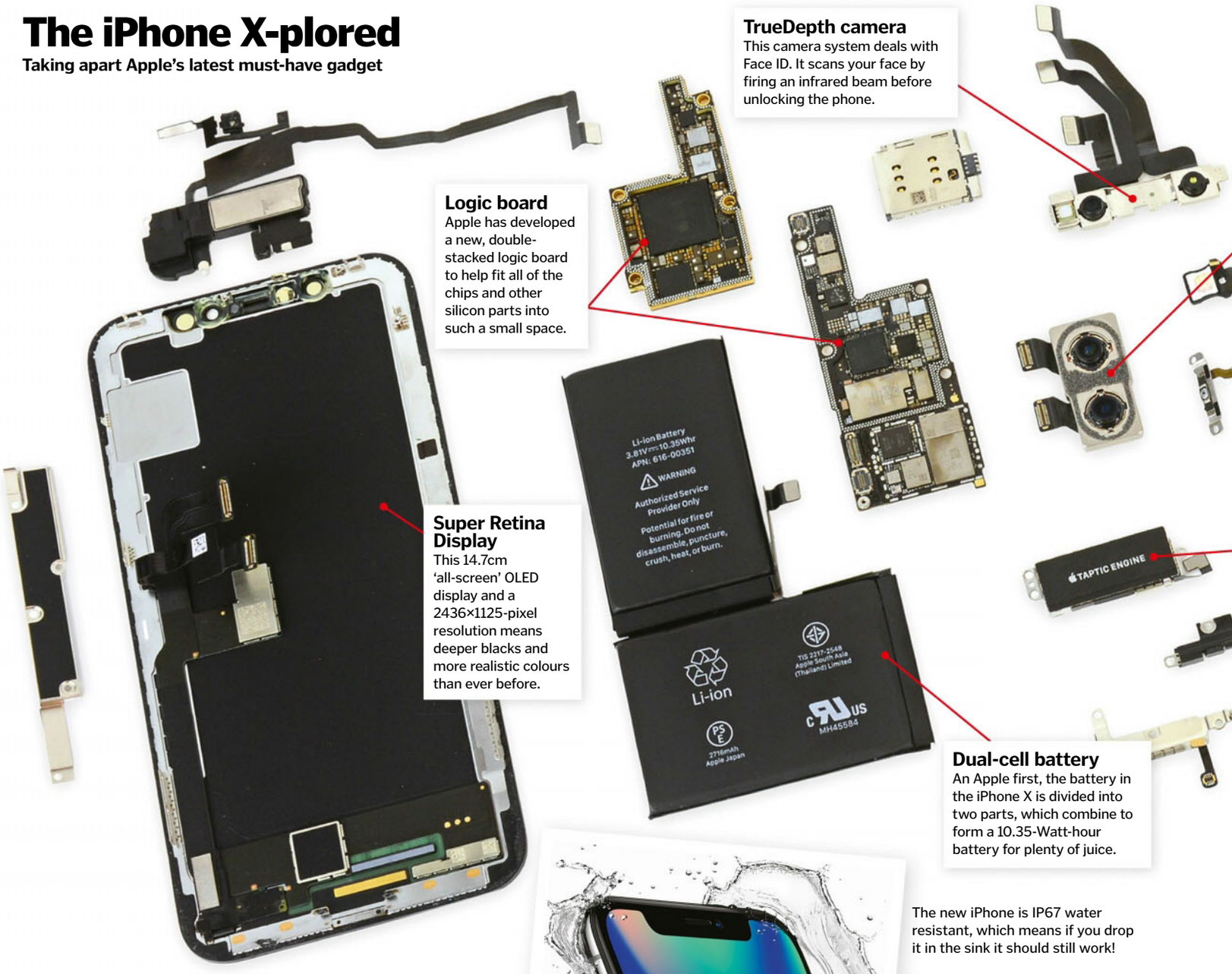
Perhaps the most impressive thing about the phone isn't the features it has – rather, it might be just how Apple managed to fit all of this cutting-edge technology into such a small device and how the battery still lasts for a full day.

The software that the iPhone X includes is just as cool. Face ID can be used to authenticate payments via Apple Pay or even to play games. One game developer has used the scanner to detect when you raise and lower your eyebrows, with a character on-screen moving up and down in unison. You'll also find an amazing camera app included, with new photography modes that can blur the background of your portrait shots, or just help you take great selfies.

Then there's the augmented reality technology, which lets you hold your phone up and see images projected over the real world, like a dinosaur strolling through your local park. Combine this all together and you have a smartphone of the future.

The iPhone X-plored

Taking apart Apple's latest must-have gadget



TrueDepth camera
This camera system deals with Face ID. It scans your face by firing an infrared beam before unlocking the phone.

Logic board
Apple has developed a new, double-stacked logic board to help fit all of the chips and other silicon parts into such a small space.

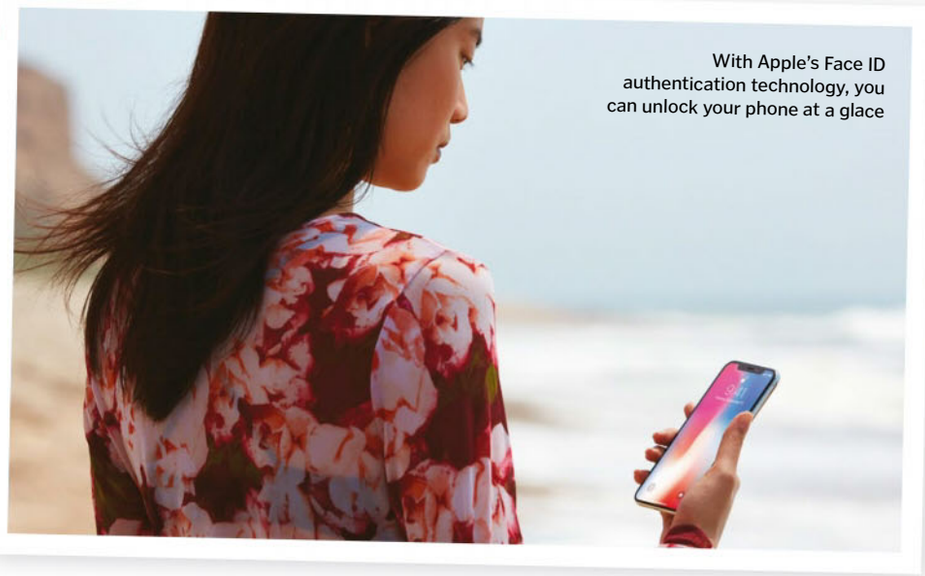
Super Retina Display
This 14.7cm 'all-screen' OLED display and a 2436×1125-pixel resolution means deeper blacks and more realistic colours than ever before.

Dual-cell battery
An Apple first, the battery in the iPhone X is divided into two parts, which combine to form a 10.35-Watt-hour battery for plenty of juice.

The new iPhone is IP67 water resistant, which means if you drop it in the sink it should still work!

How does Face ID work?

Face ID is the replacement for Touch ID that scans your face to unlock your phone and authenticate Apple Pay, and it's super smart. When you glance at your phone, a flood illuminator projects infrared light onto your face, and that image is picked up by an infrared camera. A dot projector casts out over 30,000 invisible infrared dots onto your face. These two images are combined, analysed within the phone's A11 Bionic processor, and if the phone recognises the features of your face, it unlocks your device. All of this happens in a fraction of a second. The even smarter thing is that the iPhone won't scan your face until you look at it – it can track whether you're focused on the iPhone to avoid someone unlocking your device when you're not looking.



With Apple's Face ID authentication technology, you can unlock your phone at a glace

"The Face ID sensor lets you unlock your phone just by looking at it"

Dual rear camera
Two 12-megapixel cameras allow for improved standard and zoomed shots thanks to the better sensors and optical image stabilisation.

Taptic engine
This vibration engine gives you small 'taps' of feedback when you firmly press on the screen or unlock your device.

Speaker
The speaker at the bottom of the phone also has a rubber seal to help the phone stay properly waterproof.

Wireless charging loop
This loop allows the iPhone X to charge wirelessly using any Qi-certified chargers, which is very handy.

Rear casing
The back of the iPhone X is made of glass to allow the wireless charging hardware to work more reliably.

Wireless charging will work with any compatible mat

SPACE

SHOULD WE BE WORRIED ABOUT THE DEBRIS WE'RE LEAVING IN EARTH'S ORBIT?

E JUNK

We humans are not particularly good at cleaning up after ourselves on Earth, and it turns out we may be even worse when we leave our planet. In over 60 years of space exploration, we've rapidly filled Earth's orbit with junk, and that could become a serious problem in the not too distant future.

The Soviet satellite Sputnik 1 became our first piece of space junk in October 1957 after it had become the first human-made object ever to orbit Earth. By January 1958 its orbit had decayed enough that it re-entered our atmosphere and burned up, never to cause any trouble. But since then we've launched thousands of satellites into space, and many of them have been left in Earth orbit even after they have stopped working.

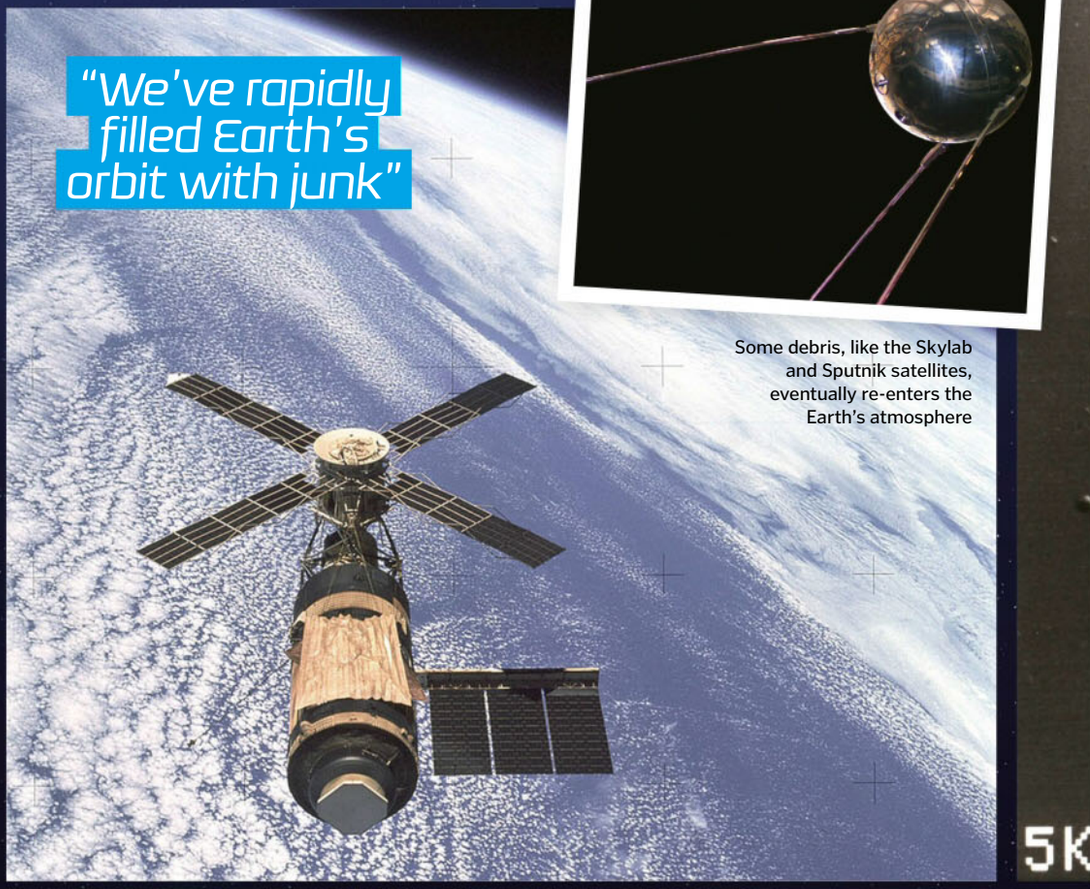
Space junk comes in all shapes and sizes, from bits as small as a fleck of paint to chunks as large as a satellite. More than 7,500 satellites have been launched into space since Sputnik 1, and over half of these are now defunct and orbiting Earth as junk. About 23,000 pieces of debris larger than a baseball are tracked in orbit, but it's estimated that there are millions of smaller pieces. Travelling at speeds of more than 28,000 kilometres per hour, their size doesn't really matter; all of these bits of space junk could cause devastating damage if they hit another object.

Space junk, like climate change, is one of those things that's hard to fathom until it's

actually a problem. Space is huge, so it seems almost inconceivable that small, human-made objects could pose any sort of problem. However, over the years we've learned that this is anything but the case, with numerous instances of collisions occurring. As a result, Earth orbit can now be a dangerous place, so hazardous in fact that satellites often need to perform avoidance manoeuvres in order to dodge debris. Satellite operators must move their satellites out of the way if a piece of debris is predicted to head in their direction. Even things as large as the International Space Station (ISS) must be moved now and again. In extreme circumstances, the crew of the ISS get in their spacecraft ready to evacuate in case debris hits the station and causes severe damage, although thankfully no evacuation has ever been required.

Hitting something large can be disastrous, as a number of events over the years have shown. In 1996, part of a French satellite called Cerise was ripped off when it was hit by debris from a ten-year old piece of an Ariane rocket. This was followed in 2009 by a defunct Russian satellite slamming into a US satellite, shattering both into thousands of pieces of debris that continue to orbit Earth today. But even small bits can pose a problem. In 2016, British astronaut Tim Peake noticed that one of the windows on the ISS had been cracked by a small piece of debris, either human-made or a natural micrometeoroid of some sort. Although not detrimental to the station, it was evidence of the danger posed.

One of the most infamous space debris events came back in 2007, when against international rules China intentionally blew up one of its own satellites with a missile. The anti-satellite test on its Fengyun-1C satellite was met with horror, as it produced a cloud of thousands of pieces of debris that engulfed Earth within two years. The debris ranges in altitude from a few hundred to a few thousand kilometres above Earth, and some of it is likely to remain in orbit indefinitely. Understandably, no nation has ever repeated this test and hopefully never will.



Some debris, like the Skylab and Sputnik satellites, eventually re-enters the Earth's atmosphere

We can track debris thanks to groups like the US Space Surveillance Network, which keeps an eye on the more than 23,000 objects larger than a baseball floating around above us. These smaller bits, one of which was likely the cause of the crack on the ISS window, are impossible to see. In an effort to get a better handle on the small debris, a device called the Space Debris Sensor (SDS) was sent to the ISS in December 2017. Comprising a flat square made of three layers, it will be used to monitor how much debris is hitting the ISS. From this it's hoped we can estimate how much of this smaller debris is in orbit. Protecting against it is much more difficult, however, and spacecraft need to have sufficient layers to ensure that in the event they are hit, those onboard can survive.

In an effort to try and limit the amount of debris in orbit, a number of guidelines have now been put in place. While these won't limit the amount of debris already in orbit, they can help us to stop adding to the problem. For example, satellite manufacturers are now required to

WHY CLEARING SPACE JUNK IS IMPORTANT

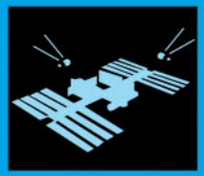
Left to orbit the Earth, space junk can go from being a nuisance to a deadly missile

Kessler syndrome

A theory known as the Kessler syndrome suggests that if too much space junk orbits Earth, one collision could cause a chain reaction of collisions as more debris hits each other.

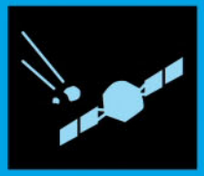
Falling to Earth

Some space junk can reach Earth, such as pieces of NASA's falling Skylab in 1979. The more space junk that's in orbit, the more chance of this happening.



It can hit the ISS

Astronauts on the ISS constantly have to be on the alert for debris. If any is found the station is moved, and in some cases the astronauts will prepare to evacuate.



High speed

Even tiny pieces the size of a paint fleck can cause damage to satellites because they travel at such high speeds, so efforts must be taken to limit this debris.

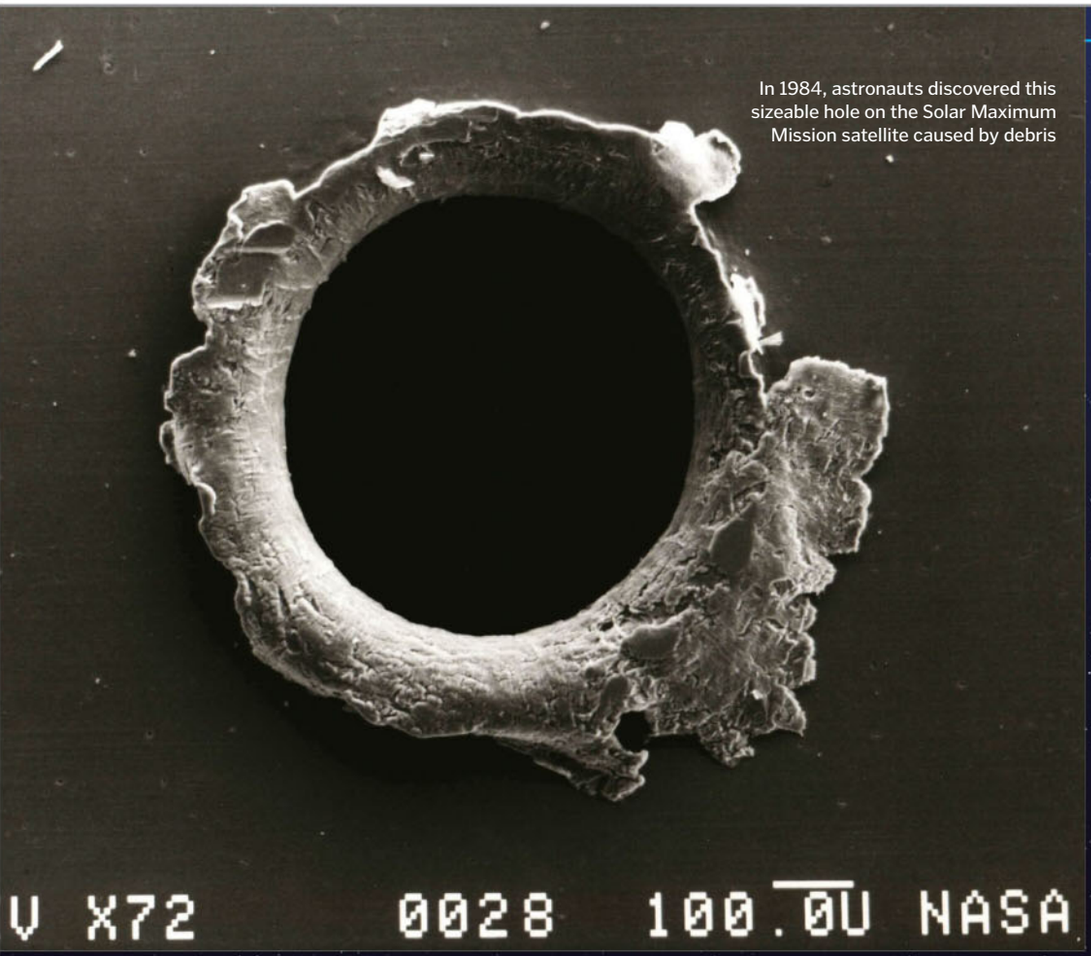
Deadly orbits

If space debris in certain orbits is allowed to build up it could render those orbits unusable, as the debris would present too significant a risk to new satellites.

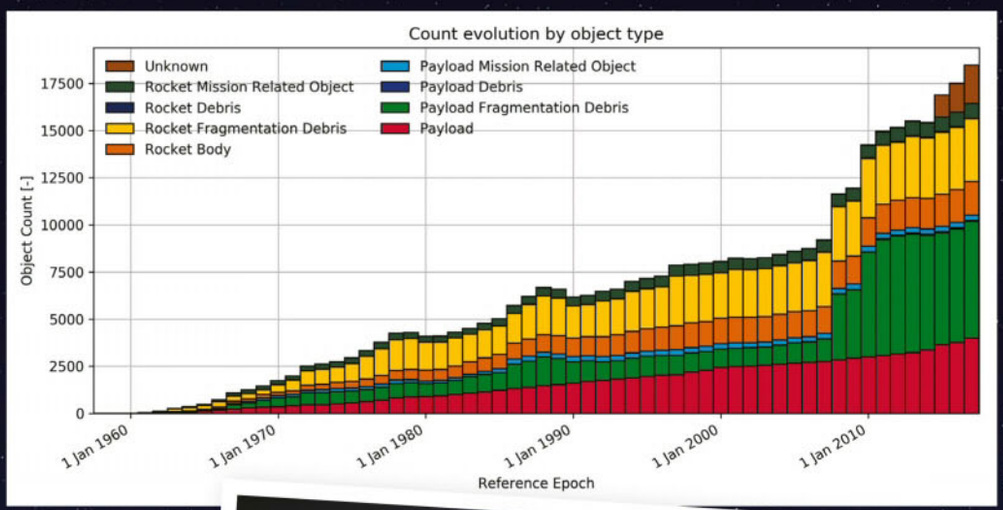
Satellite impacts

Leaving larger, dead satellites in orbit risks them colliding with others, such as in 2009 when a defunct Russian satellite collided with a working American one.

DID YOU KNOW? *The Chinese anti-satellite test in 2007 increased the amount of trackable debris in orbit by 25 per cent*



In 1984, astronauts discovered this sizeable hole on the Solar Maximum Mission satellite caused by debris



Since Sputnik 1 in 1957 we've added a wide array of space junk to Earth's orbit

The crew of Space Shuttle Discovery's STS-48 mission performed the first manoeuvre to dodge space debris in 1991

SPACE JUNK BY NUMBERS

7,500
satellites have been launched into Earth orbit since 1957

ONLY AROUND **1,200** SATELLITES ARE INTACT AND OPERATIONAL

167 MILLION
Total number of bits of debris in orbit

DEBRIS TRAVELS AT SPEEDS OF OVER **28,000 KPH**

23,000
objects are tracked regularly in orbit

MODERN SATELLITES MUST RE-ENTER EARTH'S ATMOSPHERE AFTER **25 YEARS** IN ORBIT

The estimated mass of all space objects in Earth orbit is

7,500 tons

THERE WERE **84** SUCCESSFUL ROCKET LAUNCHES IN 2017

"Earth orbit can now be a dangerous place"

CLEANING UP SPACE JUNK

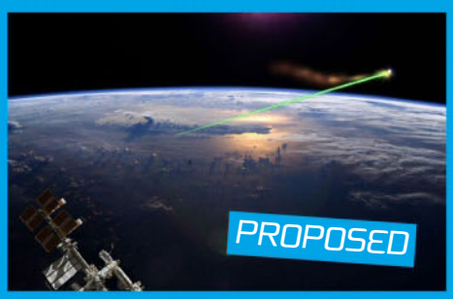
The proposals that could avert future disasters in Earth orbit

e.Deorbit

This mission is a proposal from the European Space Agency (ESA). It will involve sending a satellite with a capture device, such as robotic arms or a net, to snag a heavy, defunct satellite in near-polar orbit at a height of 800–1,000 kilometres. The e.Deorbit spacecraft will then perform a controlled atmospheric re-entry to pull the dead satellite into the atmosphere, where it will burn up.

CleanSpace-One

CleanSpace-One was a Swiss proposal to launch a 30-kilogram satellite into low-Earth orbit. It was meant to then grab a defunct nanosatellite called SwissCube with a net. However, it was supposed to launch on a now-cancelled Swiss space plane in 2018, so the status of the mission is now unknown.



Space Laser

A recent paper published by researchers at the Air Force Engineering University in China explores the impact of using a space-based laser to destroy space debris. The team used numerical calculations to target space debris under ten centimetres long with 20 bursts of light per second. This idea is just theoretical at the moment, and there are also concerns that such technology could be used as a weapon.

KITE

A mission from The Japan Aerospace Exploration Agency (JAXA), the Kounotori Integrated Tether Experiment (KITE) launched from the ISS in January 2017. The idea was to use an electromagnetic tether to produce a noticeable tug on a Japanese cargo spacecraft, pulling it into the atmosphere. It was suggested this technology could be used to de-orbit other satellites. Unfortunately, the demonstration mission ended in failure when the tether failed to deploy.

ensure their satellites burn up in the atmosphere within 25 years of mission completion, either using their thrusters to re-enter or being placed in an orbit that causes enough atmospheric drag to bring them back.

Thankfully, all is not lost for pieces of debris already in orbit. A number of different proposals have been put forward to try and clean up the mess in the hope of doing so in the future. These have included using lasers on Earth to try and push debris back into our atmosphere, where it can burn up. Others have suggested launching new spacecraft with nets or tethers onboard and using them to snag dead satellites and bring them back down. There are also suggestions to include similar de-orbit measures on new satellites to ensure they do not get stuck in space.

In December 2016 Japan launched a mission to test out such a method. Called the Kounotori Integrated Tether Experiment (KITE), the idea was to extend a tether from a cargo spacecraft and run a current through it. This would create atmospheric drag, producing a tug on the spacecraft that would gradually lower its orbit. Unfortunately, the mission ended in failure, but it's still possible that something like this could be included on satellites in the future in order to bring them back to Earth.

This is a pressing concern, as we're launching more and more satellites into space. These include cubesats (small satellites no bigger than a loaf of bread) operated by universities and other institutions that offer a low-cost way for them to reach space. Many of these have no form of propulsion, however, and a study in 2015 found that a fifth of them were violating the 25-year mission rule, either unintentionally or as a result of the orbit they were placed into.

> "Finding ways to remove debris will be crucial"

Everything we've mentioned so far points towards a much bigger problem – Kessler syndrome, something broached in the film *Gravity*. The idea is that colliding space debris could start a chain reaction of collisions in Earth orbit, destroying more and more satellites and ultimately making some regions all but unusable. It might seem unlikely, but the more stuff we throw into space, the more likely such a scenario becomes.

Space junk is a problem that's not going to go away any time soon, and with more and more satellites being launched into space, the risk of collisions rises. As our ambitions increase, we'll need to prove we're capable of keeping things tidy before it's too late.

EARTH ORBIT TIMELINE

Major events that have led to increased space junk or dead satellites

1978
Kosmos-954
This Russian satellite re-entered the atmosphere on 24 January 1978 after it malfunctioned, scattering some of its nuclear material from its onboard reactor over Canada.

1991
Collision-avoidance manoeuvre
In 1991, the Space Shuttle Discovery had to perform the first collision-avoidance manoeuvre – a practice commonly used on the ISS today – firing its thrusters to dodge debris from a Russian satellite.

1996
French Cerise military satellite
A piece of debris from an Ariane rocket critically damaged part of this French satellite in 1996, the first confirmed collision of human-made debris in Earth orbit.

2007
Chinese anti-satellite collision
On 11 January 2007, China carried out a widely derided test, using a missile to destroy one of its own weather satellites called Fengyun-1C, which sent thousands of pieces of debris into Earth orbit.

2016
International Space Station window chip
In April 2016, British astronaut Tim Peake noticed a tiny chip on a window on the ISS caused by space debris. Thankfully, it posed no threat to the astronauts on the station.

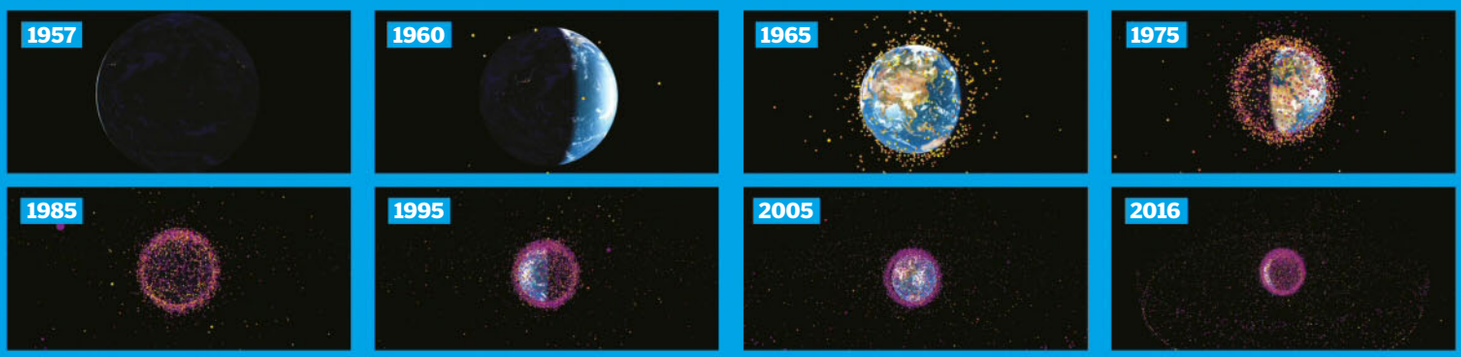
May 2013
Cubesat collision
An Ecuadorian nanosatellite called Pegasus, the nation's first ever orbital satellite, had a glancing blow in 2013 with debris from a Soviet rocket launched in 1985, sending the satellite spinning out of control.

Jan 2013
Fengyun-1C hits the Russian BLITS nanosatellite
In 2013, a small Russian satellite called Ball Lens In The Space (BLITS) was hit by space debris from the Chinese anti-satellite test, an example of the danger of producing new space junk.

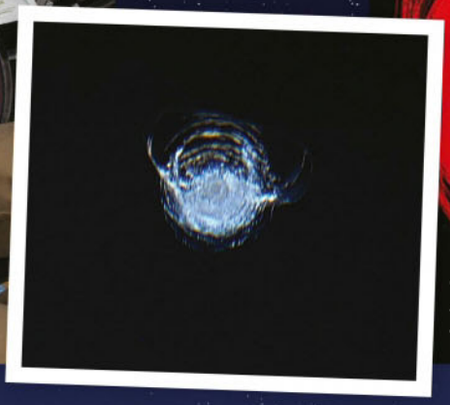
2009
Iridium 33 and Cosmos 2251
The deactivated Russian Cosmos 2251 collided with the operational US Iridium 33 satellite on 10 February 2009. Both satellites were destroyed, creating 1,000 pieces of debris larger than ten centimetres.

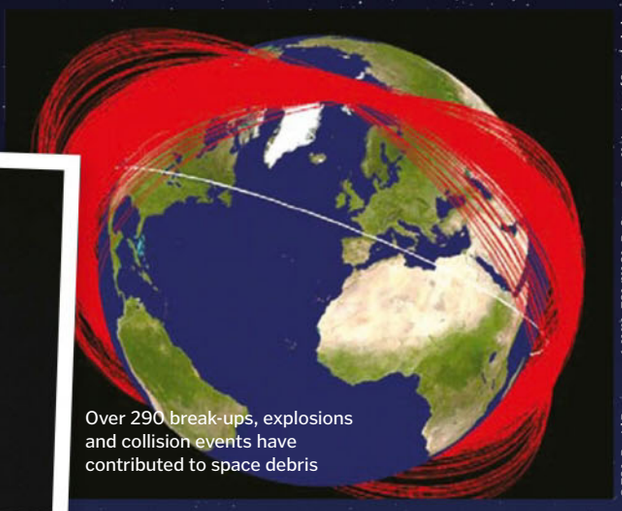
A GROWING PROBLEM

Dr Stuart Grey from the University of Strathclyde created these visualisations to show the accumulation of orbital debris since the dawn of the space age

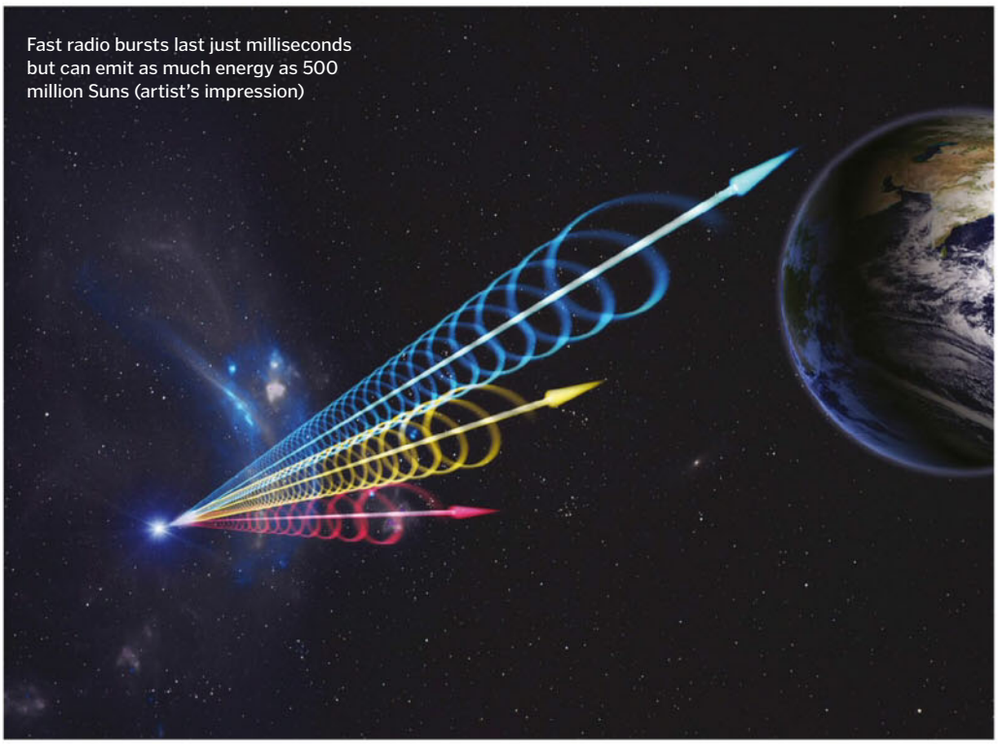


British astronaut Tim Peake spotted a tiny chip in the ISS' cupola window (below) in April 2016





Over 290 break-ups, explosions and collision events have contributed to space debris



Fast radio bursts last just milliseconds but can emit as much energy as 500 million Suns (artist's impression)

Fast radio bursts

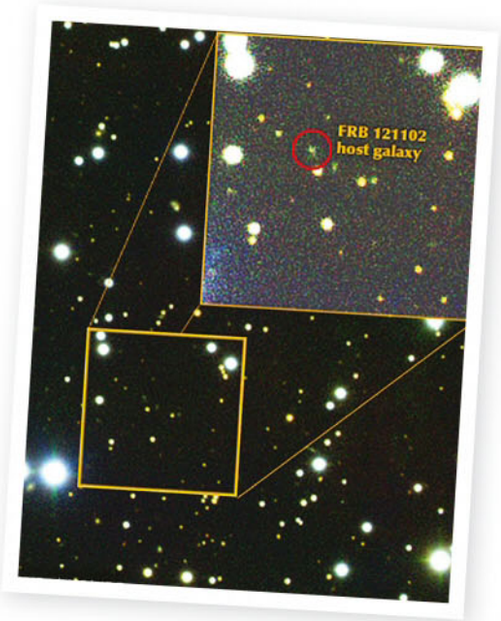
What are these mysterious blasts of energy coming from outside our galaxy?

When astronomer Duncan Lorimer and his student David Narkevic were investigating old archived files from pulsar survey data, they never expected that what they were about to discover would puzzle astronomers the world over. They had found a very strong and very brief burst of radio emission originating from outside our galaxy.

The immense bursts of energy had travelled 3 billion lightyears through the cosmos and blasted our planet before disappearing within five milliseconds. This new form of energy was detected by radio telescopes that were surveying the sky for radio wavelengths, so they were aptly named fast radio bursts (FRBs).

The method used to find these signals involves astronomers using highly sensitive telescopes that can only search a tiny part of the sky at a time. This 'needle in a haystack' approach has meant that only 30 FRBs have ever been detected. With such a small sample size, it's difficult to work out exactly what they are, but because they don't tend to repeat it is thought they must be coming from a cataclysmic source. Astronomers predict that FRBs originate from regions of space with incredibly strong magnetic fields, such as magnetars – the incredibly dense, rotating cores of exploded stars.

"The immense bursts of energy travelled 3 billion lightyears"



The only known FRB that has repeated its signal is FRB 121102 – discovered in 2012 – which appears to originate from a dwarf galaxy about 3 billion lightyears away

Globular clusters

Hunting the groups of stars living on the very edge of galaxies

Spherical in shape, these clusters of stars formed at the beginnings of the celestial circle of life. Each cluster is made up of hundreds of thousands or perhaps millions of ancient stars, each one gravitationally held together and spanning a few hundred lightyears in diameter.

These stars all formed at around the same time, born from the gases and space dust of a much younger universe. These types of clusters developed between 12–13 billion years ago, less than 2 billion years after the Big Bang. These ancient clusters can be found on the outer edge of galaxies known as the galactic halo, whereas younger, lesser-populated open clusters reside in a disc.

Stars within clusters move in a similar way to the gas molecules that formed them, colliding and continually orbiting one another. Individual stars grow in mass at different speeds depending on available gases. They can also merge with other stars.

The first cluster to be discovered was Messier 22 in the Sagittarius constellation in 1665. Since then, approximately 150 globular clusters have been discovered in the Milky Way alone, with one of the closest clusters – NGC 6397 – around 7,200 lightyears away and visible in the night sky.

One of the brightest globular clusters in the night sky is 47 Tucanae (pictured), which is made up of tens of thousands of stars

Replacing the Sun

What would our sunsets look like if the Sun were swapped out for another star?

Stars come in a wide array of celestial sizes, from dwarfs to super giants. Our local star is a yellow dwarf with a radius of 695,508 kilometres and a surface temperature of over 5,500 degrees Celsius.

The size that the Sun appears to be in the sky is referred to as its apparent, or angular diameter. As a spherical shape, any star in our sky would be measured by the angle it occupies in our domed sky. The Sun, for example, has a 0.535-degree angular diameter. Our dwarf star neighbour, Barnard's Star, however, would only appear to have a 0.106-degree angular diameter in our sky if positioned in the same location as the Sun.

When it comes to the Sun, size really does matter. Life as we know it has adapted and evolved to reside on a planet 150 million kilometres away from our mid-sized Sun. However, if our parent star were hypothetically replaced by one of its stellar cousins, our familiar sky and the planet's surface would rapidly become unrecognisable.

Were the Sun replaced by a small star such as Barnard's Star, it would leave the Earth starved of light and heat, throwing us into an ice age like no other. However, the complete opposite would occur if a red giant such as Arcturus replaced the Sun. Shining about 113-times brighter than the Sun, the Earth would fry to a crisp, leaving nothing but rock and dust in its wake. It's a good job this is just a hypothetical situation after all!

"Earth would fry to a crisp, leaving nothing but rock and dust"

BARNARD'S STAR

Discovered in 1916, this dwarf star is less than 20 per cent of our Sun's actual radius and about 2,600-times duller. If it occupied space in our sky is would have a tiny angular diameter of just 0.106 degrees.

GLIESE 581

Slightly larger than Barnard's Star, Gliese 581 has an angular diameter of 0.157 degrees. With a red dwarf star like this in its sky, Earth would be shrouded in a dim crimson light.

ALPHA CENTAURI A

Slightly larger than the Sun, Alpha Centauri A would occupy an angular diameter of 0.65 degrees. Though over 1.5 times more luminous than our Sun, its surface is slightly cooler at around 5,500 Celsius.

PROCYON

Currently the eighth brightest star in our night sky, Procyon is more than seven-times brighter than the Sun. If it should take the place of our star, it would have an angular diameter of 1.119 degrees.

TAU CETI

Nearly 80 per cent the size of the Sun, Tau Ceti would resemble a similar star to our own. Its angular diameter is 0.428 degrees.

KEPLER-35

In a galaxy far, far away, there are two G-type yellow stars similar in size to our own Sun. Should they be housed in our sky, their angular diameters would be 0.535 and 0.433 degrees respectively.

THE SUN

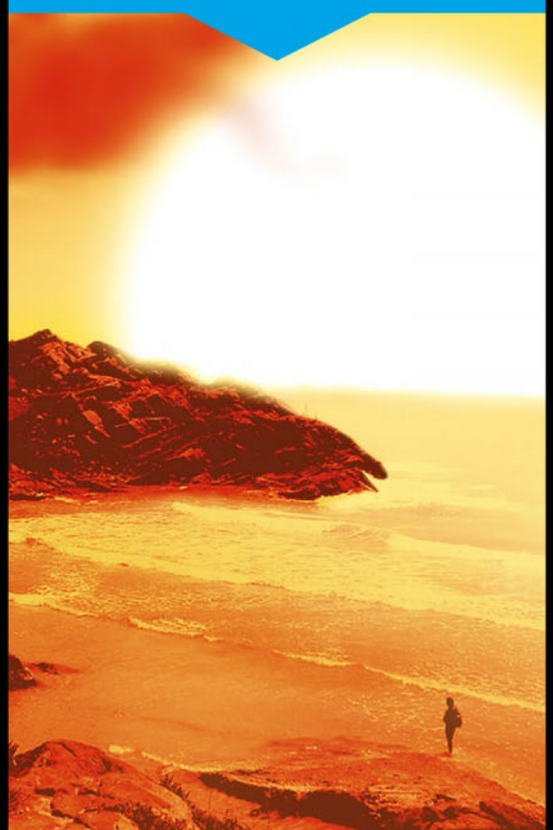
Earth's formation and the evolution of life depended on its position relative to our star, as well as its size and energy. With an angular diameter of 0.535 degrees, the Sun is at the perfect size and distance.

POLLUX

A giant in its own right, Pollux outshines and dwarfs our Sun. It is about 32-times brighter and nearly nine-times wider than our local star, and it would have an angular diameter of 4.763 degrees in our sky.

ARCTURUS

With an impressive angular diameter of 13.691 degrees in our sky, Arcturus would subject Earth to extreme heat, resulting in a huge loss of life as we know it.



ALDEBARAN

518-times brighter and 44 times the diameter of our Sun, Aldebaran would take up most of the sky with an angular diameter of 23.5 degrees.

INVASION of the BODY SNATCHERS

Welcome to the world of nature's weirdest freeloaders – it's enough to make your skin crawl

Within our bodies, lurking inside our pets and infesting our food, there are devious organisms living out their lives and surviving at the expense of others. From worms to viruses, insects to birds, parasitic species are found all over the world, with their characteristics and behaviours as diverse as they are numerous.

Parasites are some of the world's most feared organisms, and part of this is due to the fact that they possess unrivalled survival abilities. Their remarkable lifecycles are some of the most unique and intelligent known to planet Earth. We live our lives oblivious to the nefarious intentions of the microscopic nasties that manipulate their unwitting hosts into providing food, shelter or a haven to incubate offspring.

While most are just an inconvenience to their hosts (after all, it benefits them to keep us alive), some are capable of causing total devastation, flourishing in niches too hostile for other life to compete. They are able to do so due to the evolution of complex and cunning mechanisms that enable them to change their host's physiology or anatomy, thereby allowing them to invade by overthrowing immune defences or taking over their host's brain.

Parasites find their living homes and food supplies by sneaking into the bodies of their victims through undercooked meat or contaminated water, or by laying in ambush. Whether they are chewing around vital organs or obliterating brain matter, parasites are living among us and feasting on our flesh, reminding us that you don't have to be big to be powerful. These are the creepiest of the crawlies.

The mind controllers

These parasites have one aim – to get into your brain and take over. These are what nightmares are made of

The brain-eating amoeba

A tiny predator with a big appetite for brain tissue

In the depths of freshwater lakes and rivers a deadly microbe lies dormant, unbeknown to the people swimming on the surface. It is patiently waiting for the moment to build a new home inside a warm-fleshed mammal. It looks like nothing more than a blob under a microscope, but *Naegleria fowleri* is a specialised predator with an unquenchable appetite for brains. It strikes lucky when a drop of water is pushed up the nose of a host, working quickly to tunnel into the olfactory nerve, using it as a ladder to get straight to the brain.

The amoeba crosses the blood-brain barrier with ease to find its perfect home among the soft, warm and nutrient-rich nervous tissue. It begins to feast using lethal suction cups to rip up the host's brain cells and devour the insides. The host starts to lose their senses as the parasite invades the sensory nerves. The destruction spreads like wildfire and penetrates further into the brain matter, killing almost all of its victims. The host will not succumb without a struggle, but this crafty invader is safe from both its host's immune system and pharmaceutical intervention, as few medicines can reach it behind the blood-brain barrier.

The free-living amoeba can cause primary amoebic meningoencephalitis (PAM), which is a rapid-onset fatal infection of the central nervous system

The lancet liver fluke

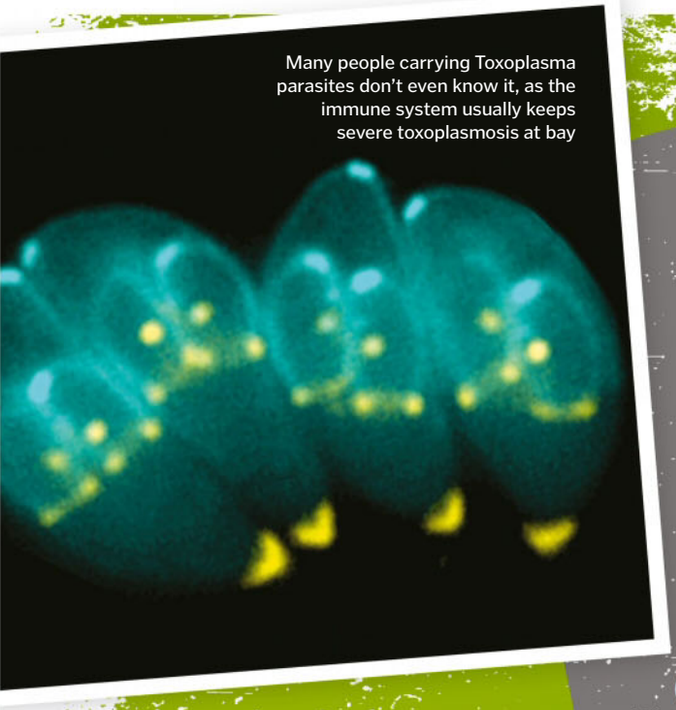
This manipulative invader turns ants into puppets

Ants will occasionally come across a particularly tempting treat – a ball of regurgitated slime from a snail. The allure of this sweet-smelling snack is irresistible, and they unwittingly gobble the hundreds of parasitic flatworm juveniles that have been waiting for their ride into a new host. Once inside, the tadpole adolescents quickly begin a terrifying raid on the body of the ant, converting it into a personal transport system.

One fluke takes control of the ant's body by nesting in a cluster of nerve cells. At the mercy of these cranial invaders, the ant climbs a blade of grass and remains there until morning, sitting in the direct path of animals grazing in the field. As dawn breaks, it climbs back down. Each night the process repeats until a cow unwittingly ingests the ant.

As the ant is consumed, the flukes burst forth to continue maturation in the cow's intestines. Now adults, they release eggs with the excreted faeces of the cow, which enter a new snail when it takes a helping of the tasty cowpat. The eggs hatch and migrate to the snail's respiration chamber, causing them to cough up a slime ball and restart the cycle.

A parasite-piloted ant is at the complete mercy of the fluke



Many people carrying Toxoplasma parasites don't even know it, as the immune system usually keeps severe toxoplasmosis at bay

Toxoplasma gondii

The single-celled parasite that can manipulate your brain

You don't need to look far to find *Toxoplasma gondii's* favourite host. As she sits innocently purring in front of the fireplace, your cat could be harbouring thousands of these formidable single-celled organisms. If you're a human, you might feel as if you've got the flu, but the fate is much worse if you happen to be a mouse or rat. Toxoplasma heads straight for a rodent's brain to manipulate it into hurtling towards danger, usually in the form of a feline.

Rodents are genetically programmed to dislike the smell of cats; the instinct is vital to their survival, keeping them from getting too close to feline predators and ending up as an appetising snack. But *Toxoplasma gondii* really muddles up the relationship between Tom and Jerry. An infected rodent no longer fears the smell of a cat's urine and is instead attracted by the aroma, which swiftly leads them into the sharp jaws of a hungry tabby. That may seem counterintuitive for the parasite, but their is a method in engineering a rat's moment of madness: the parasite has led its victim to a gruesome fate so that it can continue its lifecycle in the intestines of the cat.

The parasite invades, reproduces within and subsequently destroys any host cell it can penetrate. After wreaking havoc throughout the intestines, leaving a trail of carnage in its wake, the parasite then turns to the macrophages circulating in the blood. It hitches a lift with these white blood cells to reach the brain, where it will harden into an almost indestructible cyst.

A mammalian brain can quickly become infected with hundreds of these cysts, which change host behaviour and destroy brain tissue. The relentless attack from this intelligent intruder is almost impossible to defeat. A strong immune system can only keep them contained, but the toxoplasma will sit patiently, lying in wait for the moment when defences are down so it can strike again.

Toxoplasma lifecycle

How Toxoplasma gondii relies on its feline hosts to survive

Toxoplasmosis (A-G, below)
In intermediate hosts, the oocysts develop into a form called tachyzoites, which can invade host cells, travel to muscle and neural tissue in the body and form cysts.

E Some tachyzoites can become bradyzoites, which form tissue cysts

Mind control
Cysts that form in the brain can change the host's behaviour. In rodents this has been found to reduce their fear of the smell of cats.

D **Release & repeat**
If the host cell dies, the tachyzoites are released. They float around in the body until they are able to invade another cell.

Intermediate hosts
Toxoplasma gondii can survive in other animals, including rodents, birds and even humans, who can become infected if they eat food or drink water infected with oocysts.

C Tachyzoites make copies of themselves inside the host's cells

A Bradyzoites invade the host's epithelial cells **1**

B Bradyzoites turn into tachyzoites which can invade other cells, including macrophages

Cats are the toxoplasma's intended hosts

Reproductive cycle (1-7, below)

Once the parasites reach the cat's digestive tract they infect the wall of the small intestine and reproduce, generating millions of new oocysts, which are excreted by the cat.

5 Oocysts containing sporozoites are released in faeces

Definitive host

Toxoplasma gondii can only reproduce in members of the Felidae family, which includes domestic cats and their wild relatives.

4 The zygote develops into an oocyst

Parasitic egg (cyst or oocyst) is ingested by the host

F 6

Bradyzoites or oocysts are released in the host

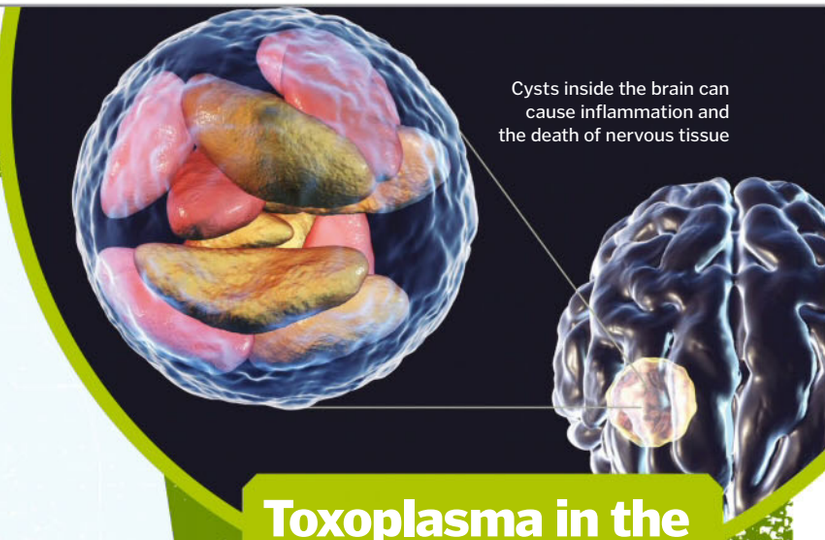
G 7

3 Gametocytes fuse to form a zygote

2 Bradyzoites form gametocytes

Infection

Cats can become infected either by eating prey that has toxoplasmosis or by ingesting the parasite's oocysts directly in contaminated food or water.



Cysts inside the brain can cause inflammation and the death of nervous tissue

Toxoplasma in the human brain

The discovery that *T. gondii* can influence a cat's behaviour and brain physiology sparked an interest in the parasite's relationship with the human brain. Research has suggested that it can cause increased aggression and impulsivity in humans, and also seems to have a significant association with obsessive-compulsive disorder, bipolar disorder and schizophrenia. It's also thought that it could impair memory.

The mechanisms for how these conditions are linked to the parasite have not yet been established, though it is thought that the infection causes brain inflammation, interference with brain receptors and the modification of immune responses.

Toxoplasma gondii structure

Inside a feline's microscopic foe

Plasma membrane
Inner membrane
Endoplasmic reticulum
Dense granules
Micronemes
Rhoptries
Nucleus
Mitochondrion
Apicoplast
Microtubules
Conoid

The body invaders

These parasites want to infest the entire body of their host, but they face an onslaught from our immune defences

The botfly

These hairy little bugs might look like any other flies, but they have much darker intentions

Don't underestimate the intelligence of a female botfly. She is so smart that she'll not only use a mammal to raise her young, but she'll manipulate another insect into doing the dirty work for her. She starts by catching a mosquito or a tick and attaching up to 50 of her eggs to it before releasing it to find its bloody meal. When the eggs sense the warmth of a mammalian host they will hatch and crawl from the mosquito into the feeding site of their blood-sucking babysitter.

If the thought of a baby botfly feeding under your skin doesn't make you itch, the thought of being able to see it moving and developing probably does. The larvae forms a tumour known as a warble in the subdermal tissue and grows over a period of six to eight weeks, completely visible to the human eye as it writhes under the skin. The painful pustule oozes fluid and doesn't heal over as the fly keeps a hole open to breathe using its posterior. The fly eventually hatches out of the host as a mature adult and flies off to continue its lifecycle without so much as a thank you.

The larvae of human botflies (Dermatobia hominis) develop in the subcutaneous layers of the skin

Crab-castrating sacculina barnacle

The barnacle that castrates then cruelly modifies male crabs to raise her young

As you read this, somewhere in the world a female sacculina larva is inching towards a male crab. When she reaches him a nightmare of utterly unimaginable proportions will begin for this most unfortunate crustacean.

Sacculina are a type of barnacle, but not the sort that stick to the side of ships and gently wave their soft feeding feet in the water. No, this barnacle wants to brainwash a male crab. She starts by shedding her outer shell before injecting her soft body through a small joint in the shell of the crab, weaving roots between the innards and organs of her host. She will then release hormones to chemically castrate the male crab by destroying his gonads. This brutal manoeuvre will also change his appearance to resemble the female of the species, inducing him to begin the female mating dance.

As the sacculina grows she makes a sac that hangs from the crab's thorax, which she fills with eggs before waiting for a male of her species to fertilise them. It's a disturbing thought. As far as the male crab is concerned, he's now a protective mother to the parasitic imposter's offspring. He will soon find a high rock and release the fertilised eggs in a cloud, starting the terrifying cycle again.

Destroying the gonads can mean making entire generations sterile, which is bad news for crab populations

Ascaris worms

These wily, wiggly invader will journey through your vital organs on their path to adulthood

These nifty worms use your circulatory and lymphatic systems as canals to transport themselves around the body. They are unnervingly common and can be found infecting humans, our pets and the animals in our food chain. They are the most common of all worm infections in humans around the world.

An ascaris worm starts life as an egg in the intestines of a host, but it is immediately evicted by its parents, forced out along with its siblings in a pile of faeces. The hardy eggs can survive for up to 15 years as they are resistant to extreme temperatures, chlorine, acid and UV exposure. They will find a host and start an epic migration from the intestines, through the blood to the lungs. Here, the hatchlings can break into the lung's alveoli and travel to the trachea, where the host may cough them up and swallow them, sending them back down to the intestines once more. While this takes just a few days, for the larvae it is the journey of a lifetime – once it reaches maturity it won't be moving again.

Ascaris worms thrive inside the intestines of their host by excreting a protective substance to stop them being digested and by swimming against the current when their host tries to defecate. Their survival mechanisms are so effective that the worms can degrade a host's intestinal tract into nothing more than a disgusting mass of moving spaghetti.

Feeding from faecal fluid might not sound pleasant, but these worms enjoy this revolting dish so much that they even copulate in it, with female ascaris worms producing up to 200,000 eggs a day! These nasty parasites may have limited vision, but they have an impressive set of chemosensors that allow them to seek out food and a mate, enabling the body-invading cycle to start again once their offspring escape the host they are born in.

Fighting ascaris in developing nations

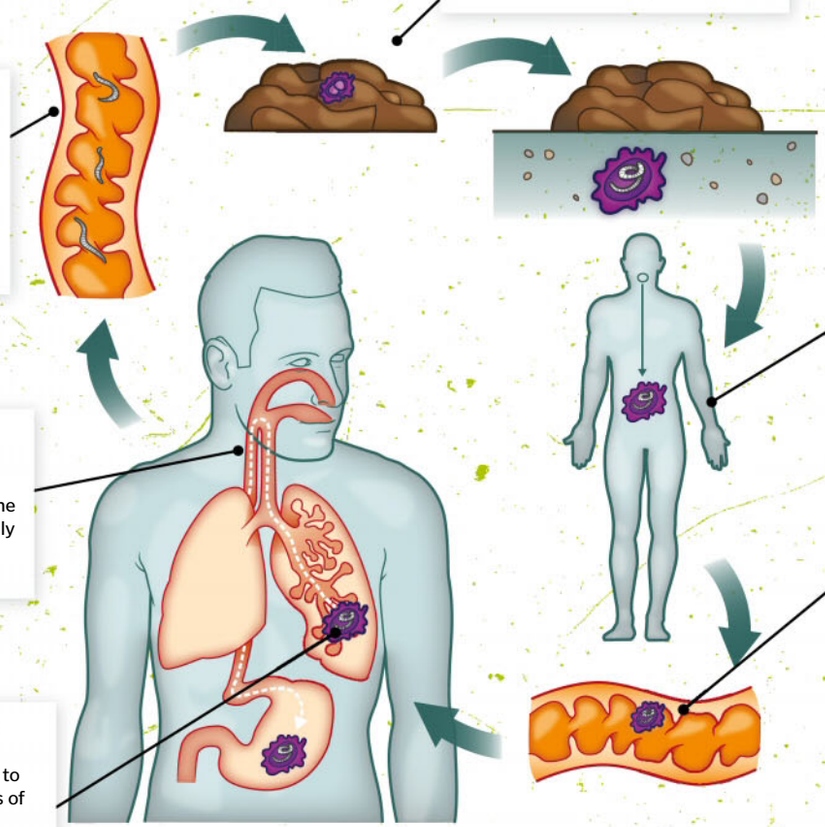
In most countries access to ascaris treatment is limited, resulting in a lot of pain, malnourishment and even cognitive development delays for those suffering with it. Intestinal worms infect up to ten per cent of the developing world and ascaris worms take the lives of around 60,000 people every year. These parasitic infections have a domino effect on the people they are infecting, preventing them from attending school or work and thereby perpetuating the poverty cycle.

While scientists have made progress in winning the war again ascaris by using a multi-pronged attack of deworming medication and improving sanitation facilities, there is still so much work to be done to free the remaining estimated 1.2 million people still infected by this ruthlessly efficient worm.

The parasites' large size can mean they compete with their human host for nutrients, causing deficiencies, particularly in children

How ascaris attacks

The lifecycle of these parasitic worms explained



Egg dispersal
The ascaris' eggs are passed by the host in their faeces, where they can also contaminate nearby soil or water.

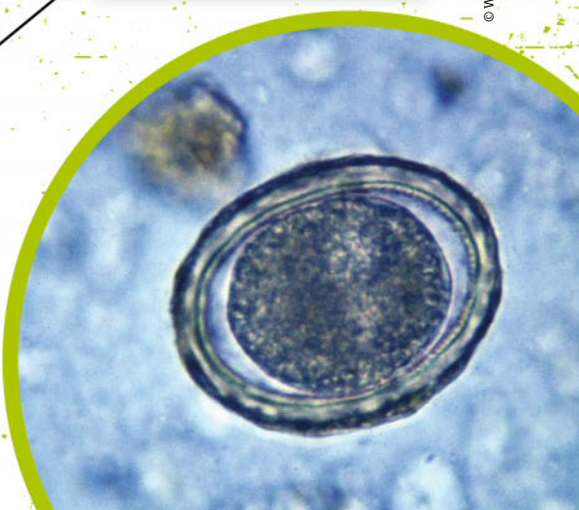
Human host
Ascaris worms can enter a human host via contaminated food, soil or water that contains the parasite's fertile eggs.

Hatching
Once the larvae hatch inside their human host, the worms invade the intestinal wall, where they can travel to the lungs via the bloodstream.

Development
In the lungs, the parasites continue to mature in the walls of the alveoli. After around ten to 14 days they travel up through the lungs to the throat.

Return to the intestines
Once the worms reach the throat, the host can unwittingly cough up and swallow them.

Fully mature
The worms return to the intestines via the digestive system, where they can fully mature and begin to reproduce.



Fertilised ascaris eggs can survive for years, ready and waiting to be inadvertantly ingested by a host

The blood suckers

While some of these exotic parasites aren't interested in us, others live closer to home and want to suck our blood

Emerald wasp

The terrifying siren of the insect world that buries their victim for their offspring to eat alive

The emerald wasp hides a gruesome secret behind her captivating shades of green. She is keen to get the freshest meal for her baby, and in order to do so she will first find a particularly unlucky cockroach with which to inject a paralysing venom that will immobilise it while she performs precision neurosurgery. Having felt around the brain to find the exact spot to deliver the cocktail of chemicals that will allow her total control over the helpless bug, she floods it with chemicals that make her victim devoid of willpower.

Next, she leads her zombified babysitter off to an appropriate location before burying it alive, and all the while the cockroach's lack of a survival instinct prevents it from putting up any resistance. Once the cockroach is sufficiently covered, the wasp attaches a single egg to the leg of the cockroach before sealing it inside the burrow she has dug.

Over the next few days the growing terror will emerge and crawl into the cockroach's abdomen, feasting on its internal organs in a specific way that will keep it alive for as long as possible. The adult wasp will then burst out a week later, leaving behind the empty carcass of its first victim, which will have spent its last hours twitching as it was eaten alive.

An emerald wasp uses its stinger to inject powerful toxins into a cockroach's brain

The beautiful allure of the emerald wasp's colourful exoskeleton is misleading

Leeches have been used in blood-letting therapies for over 2,000 years

Leeches can eat so much in one sitting that they can go without food for up to a year!

Leeches

An adaptive and resilient hitchhiker who loves a meal of blood

Blood-sucking leeches are segmented worms that get a pretty bad press considering they have been used medically for centuries. They are amazing feats of biology, containing both female and male reproductive organs in one individual, and these dark, slimy creatures have actually helped us with reattaching limbs, reducing swelling and dissolving blood clots.

While their undulating crawl may be unnerving, they are mostly harmless, simply wanting to give their host a nibble before moving on. A leech takes blood by clamping its jaws – consisting of three blades angled at one another – onto the skin of the host then using suction and mucous to stay attached, all the while releasing a chemical called hirudin to encourage the wound to keep bleeding.

Scientists also suspect that leeches unleash anaesthetic into the blood, a tactic that prevents their host from realising they're there. This allows the leech to stay attached until it is full, at which point it will fall off and begin digesting its meal.

Hard ticks

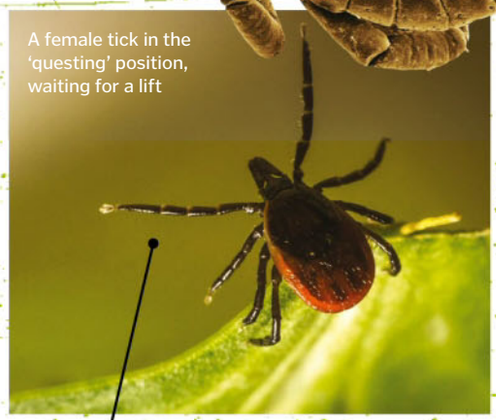
The vampiric ectoparasite that can only survive by drinking blood

One of the most adaptive and resilient hitchhikers of the gruesome world of parasites is the hard-bodied tick. These hard-shelled masterminds rely on your blood because they lack sufficient energy to complete their lifecycle without indulging in a warm, crimson feast. They're brought into the world as eggs unable to grow without latching onto a host, so they must find a small mammal or lizard in order for them to start developing.

The larva engorges itself on the fresh, warm blood of its first host before dropping to the ground exhausted and overindulged. They're equipped with ferocious jaws yet unable to jump, so they can only lay in ambush when they need to feed again. They stretch out their clawed first pair of legs and then wait for an animal to pass, at which point they grab hold. When seeking their prey they wave their legs, looking for a signal that there is a host nearby.

You're an easy target. She knows you're there – the special sensory organs within her limbs can detect the carbon dioxide in your breath and the ammonia in your sweat. You're getting closer, and suddenly she senses a spike in temperature, her cue to reach for opportunity and latch onto your skin with her tiny claws.

Beneath the protective plate guarding her soft body she is armed with a set of sword-like jaws. She settles somewhere after seeking out her favourite spots to lounge for a few days and punctures the skin with a miniscule, pointed tooth, allowing her saliva to ooze into the wound and keep your skin bleeding.



A female tick in the 'questing' position, waiting for a lift

Tick anatomy

How these tiny parasites satisfy their bloodlust

Feeding tube

Many ticks have barbs on their feeding tubes to secure themselves to their hosts as they feed, while some species also secrete a cement-like substance to stay fixed in place.

Questing

Ticks are unable to fly or jump, so when in search of a host they will hold onto leaves or grass with their hind legs. With their front limbs outstretched they are ready to grab hold of a passing creature.

Painkillers

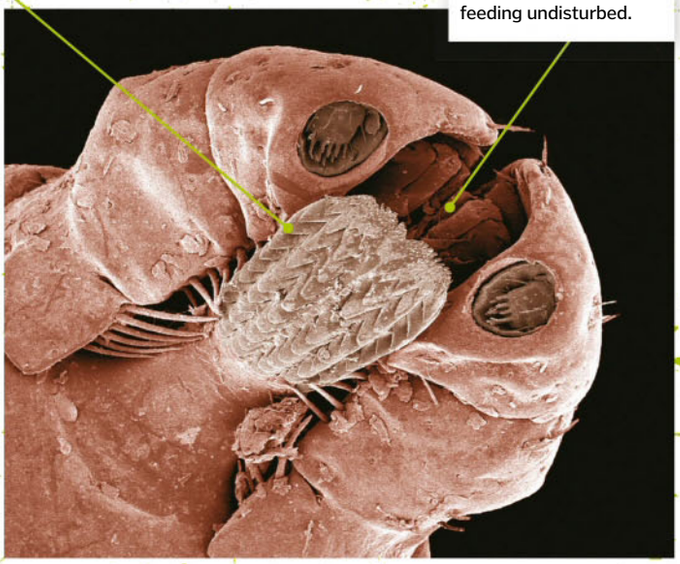
Anaesthetic compounds in a tick's saliva help numb the pain of the bite so the host may not even notice the tick, enabling the parasite to continue feeding undisturbed.

Hard tick

There are hundreds of tick species divided into two categories. A hard tick has a tough plate on its back called a scutum, and its mouthparts (capitulum) are visible. A soft tick does not have a scutum, and its capitulum is not visibly separate from its main body.

Big appetite

Ticks can feed for a few minutes up to a couple of hours. Some species swell dramatically while feeding due to the amount of blood they have ingested.



An engorged tick can become so full that it can't move

Diseases transmitted by ticks

If you find that a tick is having a nibble on your skin, it is important to resist the urge to just pull it off. It's embedded pretty deeply, and there is a risk of accidentally forcing the tick to vomit blood into your system. This could be riddled with disease. Ticks are known to transmit diseases including babesiosis and lyme. Instead of yanking this unwanted clinger-on off your skin, use thin tweezers to grab the tick as close to your skin as possible and gently pull it out, directly up from the skin. If you would like to check that the tick hasn't exposed you to anything nasty, you can put it in a ziplock bag to have it checked by a medical professional if needed. If you do develop a rash or a fever in the weeks after removing a tick, go to the doctors as soon as possible.

Norman Borlaug

The man who saved a billion people from starvation

Dr Norman Borlaug holding up stalks of his life-saving crossbred wheat

Pulling a cultivator across a barren field in the midday heat with a rope harness strapped across his chest, Dr Norman Borlaug was clearly not a conventional scientist. He had given up his comfortable life in Delaware in 1944, leaving a cosy family life behind to sleep on the floor of a rat-infested warehouse in a Mexican wheat field. Only able to drive into town once a week, he lived in uncomfortable conditions, with poor-quality water causing regular episodes of dysentery.

Over the next 16 years he would dedicate his life to solving the wheat production problems plaguing the country and train a whole generation of young scientists, transforming agricultural production worldwide. Borlaug went from Iowa farm boy to pioneering the 'green revolution', his commitment and devotion saving countless lives the world over in his pursuit to end world famine.

From the age of seven Borlaug had worked on his family's farm in Iowa, spending his days hunting, fishing and rearing livestock, in addition to learning how to cultivate corn and oats. His education was confined to a one-room one-teacher rural school house in Howard County, but from these humble beginnings he would go on to change the world.

He graduated from the University of Minnesota in 1937, working between his studies with the unemployed on Federal projects. He began working as a microbiologist at DuPont in Wilmington, Delaware – originally to research industrial pesticides and preservatives – but his laboratory was converted into a research station in response to the 1941 Pearl Harbour attack. He worked under the United States armed forces until 1944, when he accepted a position as a geneticist and plant pathologist leading the Cooperative Wheat Research and Production Program in Mexico.

Throughout the country Borlaug witnessed barren land that had been completely stripped of nutrients after centuries of ploughing. His project sought to create crops to suit the challenges of the local soil. He started by

A life's work

The incredible life of Norman Borlaug and his quest to provide food to those living with famine

1914
The great-grandchild of Norwegian immigrants, Borlaug is born into a small Norwegian-American community in Saude, near Cresco, Iowa.

1933
Borlaug is accepted at the University of Minnesota's two-year General College after failing the entrance exam for the university.

1937
Receives his bachelor of science in forestry after transferring to the College of Agriculture.

1942
Earns a PhD in plant pathology and genetics following his master's of science degree in 1939.

1942
From 1942 to 1944 he works as a microbiologist at DuPont in Wilmington, Delaware, originally to lead research on industrial and agricultural pesticides and preservatives.

THE BIG IDEA

Miracle seeds

Borlaug and his team set to work by removing the anthers of some of the wheat with a desirable characteristic. With this pollen-producing part of the plant removed, wheat plants with a different desirable characteristic were opened and the pollen removed before being placed into a bag covering the original stem. It wasn't always successful, but when it worked this process would produce hybridised wheat with both characteristics, producing strains that had a number of traits that made them better able to thrive, including disease resistance and increased yield.

Today, wheat takes up more land than any other food crop

exploring the potential of breeding a strain of wheat that was resistant to the fungal 'wheat rust', a disease that could devastate crops. Within 20 years Borlaug was successful, developing a high-yielding, disease-resistant wheat that would completely revolutionise global food production.

The resulting seeds were a miracle. They could return a high yield of double or treble a conventional crop when accompanied with chemical fertilisers. However, Borlaug was not content simply working the fields and within his laboratory, instead stepping up as a humanitarian to distribute the new strains to feed the hungry around the world.

His discoveries and creations generated a sensational enhancement of agricultural productivity that swept the globe in the 1960s. This revolution allowed countries including Bangladesh, India and Pakistan to avert famine and establish an economy in exporting grains. His work relieved millions of people from the clutches of hunger. He would die in 2009 in Dallas, Texas, at the age of 95, arguably having helped save more lives than anyone else in human history.

A farm worker displays grains of Borlaugh's wheat at an experimental facility in Ciudad Obregón, Sonora, Mexico

Norman Borlaug gives a thumbs-up as he receives the 2004 National Medal of Science Laureate from US President George W Bush

"We're going to teach you how to be rebels. Not with guns and daggers but with science and technology"

NORMAN BORLAUG

5 THINGS TO KNOW ABOUT... NORMAN BORLAUG

1

He worked with the US armed forces

Norman Borlaug was involved in the development of glue that could withstand warm salt water, among other projects with the military.

2

He was awarded the US Congressional Gold Medal

In July 2007, President G W Bush presented the Congressional Gold Medal – the highest civilian honour bestowed in the United States – to Borlaug for his role in the green revolution.

3

His project faced almost impossible obstacles

The facility in Mexico lacked scientific equipment and trained staff, and the project originally faced some resistance from local farmers.

4

He was a distinguished professor of international agriculture

Borlaug took up a position with Texas A&M University in 1984, where he taught and conducted research until his death.

5

He had a wife and family

Borlaug and his wife Margaret had three children, five grandchildren and six great-grandchildren.

1944
Flies to Mexico City to head the new programme as a geneticist and plant pathologist, where he leads the project.

1956
Breeds what become known as 'miracle seeds' of high-yielding dwarf varieties. These help Mexico to double its wheat production.

1963
95 per cent of Mexico's wheat crops are by now using semi-dwarf varieties – the harvest is six-times larger than in 1944.

1964
Appointed the director of the International Wheat Improvement Program at El Batán, Texcoco.

1970
Awarded the Nobel Peace Prize for contributions to the 'green revolution'.

1974
India becomes self-sufficient in the production of all cereals. The technology spreads to North Africa, Latin America and the Middle East.

2009
Norman Borlaug dies having spent his last years teaching at Texas A&M University.

Mexico's poison cave

Toxic gas and falling acid has not prevented some species from calling this cave home

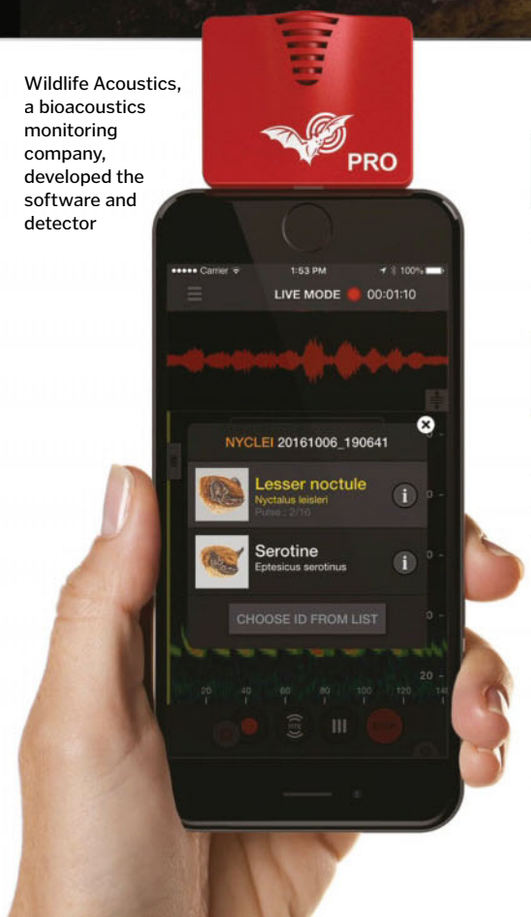
In the south of Mexico lies the Cueva de Villa Luz, a mysterious cave that should be entered with caution, for life is not made to feel particularly welcome here.

The first clue that this cave is deadly is its smell, a rotten egg odour that's enough to turn your stomach. This serious stench is the product of a lethal gas. Rising from the strange, cloudy water within, hydrogen sulphide is expelled from thermal sulphur springs beneath the water. Yet despite being highly toxic, this gas has inspired some hardy species to root themselves to the cave's roof. Here, a sulphur-metabolising bacteria collects in the form of mucous-like stalactites commonly known as 'snottites'. These protrusions also add to the danger level of these caves by dripping sulphuric acid onto the floor.

Surprisingly, this level of toxicity is homely for some species. The fish *Poecilia mexicana* is particularly impressive, as it can detoxify hydrogen sulphide thanks to a gene that codes for a protein to break it down. It's a harsh place to live, but some species have managed to make it work.

Bacteria that thrives under these toxic conditions collect to form these 'snottites'

Sulphur-rich waters rise through the floor, meeting the streams that flow into the cave



Wildlife Acoustics, a bioacoustics monitoring company, developed the software and detector

Bat detectives

The bat detector app that can tell you who is flying by

Much like the human voice, bats can have a unique frequency to their calls, though we can't always hear them. As their method of navigation (scientifically known as echolocation), it is well known that bats use sounds to help get from A to B. They use this ability like a built-in sat-nav, which involves emitting sound waves that will bounce off an object before travelling back to the bat, who can then use these signals to work out its position.

Until now these calls and clicks have usually been beyond the audio range that our ears can detect, but the Echo Meter Touch 2 PRO is changing things. Using an ultrasonic microphone it can convert a bat's calls for human ears and also find out what species they are. Unlike traditional bat detectors, this smartphone gadget records the calls of bats at different frequencies and then compares them to a database of saved recordings to confirm a match.

Currently, the app is able to detect different species of bat found in Europe, the Americas and South Africa. Whether it's the brown long-eared or the greater horseshoe, the Echo Meter works like Shazam for bats, listening to their songs and then revealing the artist.

© Alamy; Thinkstock

Unlike earthquakes, frost quakes rarely cause significant damage

Frost quakes

What causes these seismic events that shake the ground and create a loud boom?

A frost quake, or ice quake (scientifically known as a cryoseism) is a rare, natural phenomenon that makes the ground shake in the immediate proximity of its epicentre and produces a loud booming sound. These kinds of tremors are very similar to earthquakes, but the meteorological and geological conditions at work make them very distinct events.

Frost quakes occur in areas susceptible to cold air masses. Usually there is some snow covering on the ground, but only around 15 centimetres – not enough to insulate the ground. For a frost quake to happen, the ground must become saturated, which could occur after a heavy downpour of rain or from a thawing of ice or snow. When such a large quantity of water seeps down into the soil or bedrock, the ground inevitably becomes very wet. If this is followed by a rapid drop in temperature, a deep freezing of the ground occurs, resulting in the underground water freezing as well.

Water expands as it freezes, which in the case of the underground moisture puts enormous stress on its surroundings. As this pressure increases, a buildup of explosive stress is finally relieved in the form of a frost quake. A loud rumbling can be heard as the ground shakes and cracks, and tremors can be felt nearby. In the aftermath, cracks can be seen close to the epicentre. Frost quakes can cause damage, but not on the same scale as an earthquake; these icy tremors release far less energy.

Cryoseismic booms

The step-by-step formation of a cold quake

STEP 1

Water becomes trapped

When water seeps into soil and bedrock after a heavy downpour of rain, it becomes trapped underground. Water can also become trapped underground when ice or snow begins to thaw, trickling down into the soil and bedrock.

STEP 2

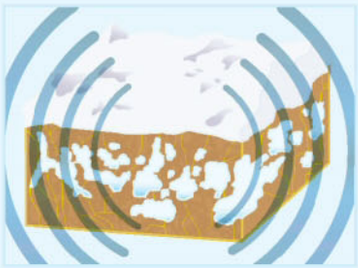
The water freezes

In cold-weather months when temperatures plummet, the saturated ground rapidly freezes. This sudden, deep freezing of the ground not only results in frozen soil and rock, but the water beneath the surface also turns to ice.

STEP 3

Pressure builds

The freezing water begins to expand underground, consequently putting more and more pressure on the soil and bedrock that surrounds it. As explosive stress builds, fractures in the rock occur.



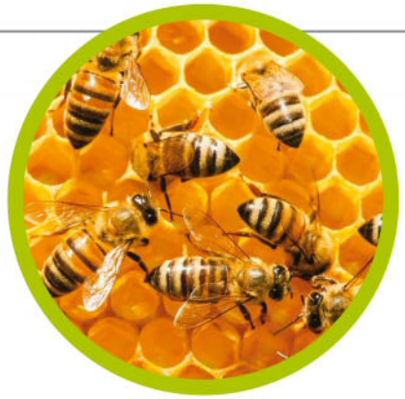
STEP 4

The soil cracks

When the explosive stress is finally relieved, a loud bang can be heard, similar to an explosion or gunfire. Shaking vibrations, much like those that occur during an earthquake, can also sometimes be felt on nearby land.

A buzzing business

How do honeybees manufacture honey and why do they make it?



A single colony of bees can have tens of thousands of members

It's a well-known fact that honeybees make the silky, golden delight that is honey, but how exactly is it manufactured? Zipping from one flower to another, honeybees perch themselves on petals and extract the sweet nectar within. It is here that the production of honey begins.

Storing the nectar in a separate 'honey stomach', enzymes within start transforming nectar into the beginnings of honey. Known as the 'bee enzyme', or invertase, it converts the sucrose sugar in nectar into simple sugars – glucose and fructose. Upon returning from their forage, these bees will regurgitate the contents of their honey stomach, giving it to other worker bees in the hive. These bees will then process the sugary solution by repeating the process of ingestion and regurgitation until their enzymes complete the conversion. This sugary solution is much less viscous than the thick honey we recognise spread on our toast.

Honey only contains around 17 per cent water. Therefore, in order to remove the excess water, bees continually beat their wings to dry it out. Once completely processed, the product is stored in the iconic hexagonal cells within the hive. The trick to keeping long-lasting honey is to store it in an airtight location, thereby reducing the possibility of contamination. Bees will seal the honey in each cell with beeswax, which is secreted from specialised glands on their abdomens.

This systematic approach to production mirrors that of our own manufacturing lines, but why do they even make honey? After all, they don't naturally do it to feed human demand.

Unlike their close relatives, the bumblebee and wasp, honeybees do not hibernate during the winter months. This means that they will require a source of nutrients when food isn't readily available. Therefore they continuously produce honey – provided there is still space for it in the hive – in order to sustain themselves once flower nectar is taken away with the end of summer.

> *"This systematic approach to production mirrors that of our own manufacturing lines"*

Past its 'cell-by' date?

One of the oldest examples of honey was discovered in an ancient Egyptian tomb. Incredibly, it was still edible, which begs the question of why honey doesn't spoil. The answer lies in two main properties of honey.

The first is its lack of water. In order for microbial growth to occur a certain level of water is required, which is known as a substance's water activity. At around 17 per cent water, honey has a water activity of 0.60: bacteria and fungi require an activity of around 0.91 and 0.70 respectively in order to survive.

Acidity is the other key factor in the preservation of this golden wonder. Honey has an average pH of 3.9, which prevents bacteria from growing in this acidic environment. This all means that honey can last for over 3,000 years, as proven by the examples left by the sweet-toothed Egyptians who produced it all those millennia ago.

Scientists are investigating whether honey's antimicrobial properties could help in the fight against drug-resistant bacteria

The honey factory

What makes up the busy business of honey production?

Honey cells
These cells hold the rewards of a hard day's work. An average hive can produce around 11kg of honey a year.

Waggle dance
In order to get the best nectar, bees communicate flower locations by 'waggle dancing' to indicate the direction and distance of a food source to other bees.

Pollen cells
Honey isn't the only food stored in hives: pollen mixed with nectar or honey is left to mature before consumption.

Brood cells
The queen will lay her eggs here. Bees develop at different rates: 24 days for drones, 21 days for worker bees and 16 days for queens.

Beeswax
Wax secreted from the bees covers the cells to keep them airtight. This is the same wax that forms the structure of the hive's hexagonal cells.

Hardened honey

After a while honey may look like it's starting to go 'bad', forming sugary crystals, but in fact this is a sign of very good quality. Honey is saturated with sugars, which will naturally separate from the solution they're held in by forming crystals. This process is aided by the temperature honey is stored at.

When honey is in a cooler environment it will form these crystals – even in the hive these crystals will form when the outside temperature drops below ten degrees Celsius. Moving crystallised honey to a warmer environment will return it to its original, runny state.

Grains form in a range of sizes and quantity depending on the rate of crystallisation

Queen bee
As head of the hive, the queen bee is continually followed around by attendants, who will feed and clean her. Her only job is to lay eggs.

Located just above a bee's main stomach is a crop, or honey stomach (pale yellow) which is used to hold nectar

HOW IT WORKS

THE BATTLE OF BRITAIN, 1940


MESSERSCHMITT
BF 110
HAWKER
HURRICANE

SOLAR-POWERED PLANES

Discover the technology and teamwork behind the first zero-fuel round-the-world flight

In July 2010, the experimental aircraft Solar Impulse took to the skies. While it was not the first solar-powered plane, the team behind the Solar Impulse project had achieved a historic feat – they had harnessed the power of the Sun to perform a 26-hour flight, including nine hours overnight. This prototype set eight world records, but it was soon eclipsed by its successor.

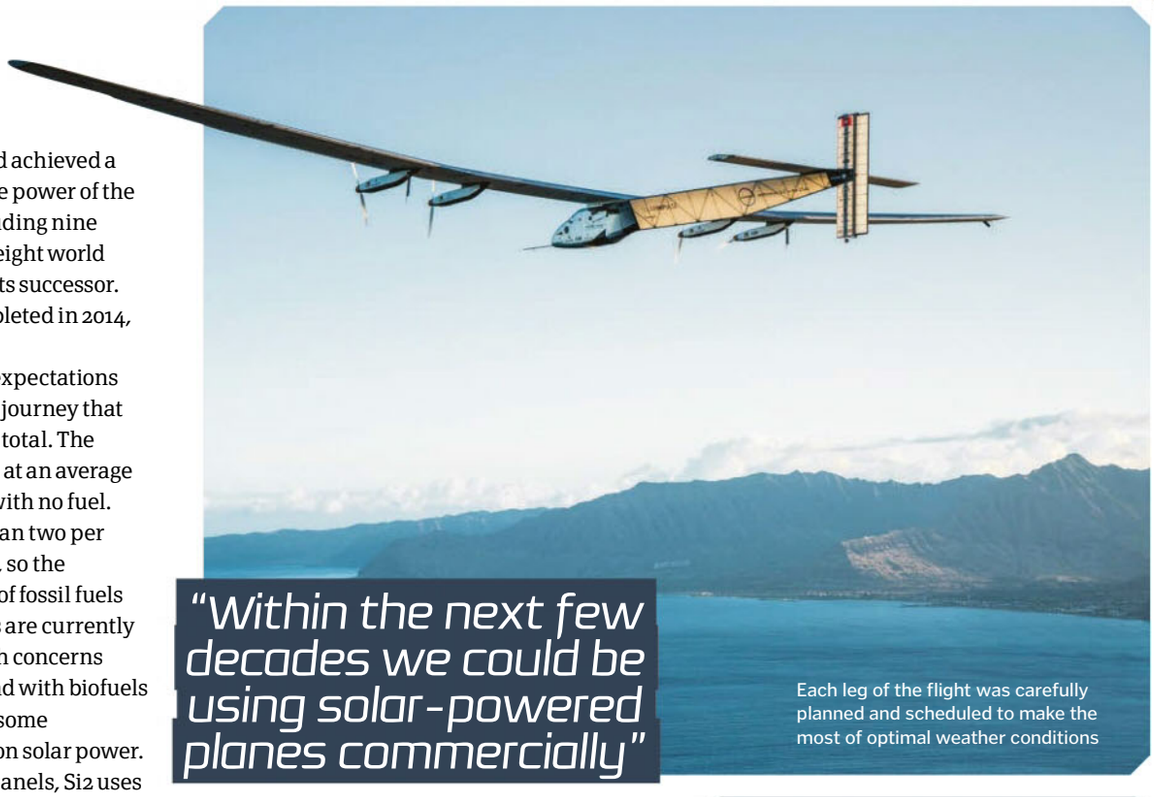
The Solar Impulse 2 (Si2) was completed in 2014, built to perform the first zero-fuel circumnavigation. Si2 exceeded all expectations and flew around the world in a 17-leg journey that took 558 hours and seven minutes in total. The team covered over 43,000 kilometres at an average speed of 75 kilometres per hour, all with no fuel.

Aviation is responsible for more than two per cent of the world's carbon emissions, so the pressure is on to reduce the amount of fossil fuels being used. Engineers and scientists are currently exploring a range of options, but with concerns surrounding hydrogen fuel safety and with biofuels yet to break into the aviation sector, some manufacturers have set their sights on solar power.

Just like with domestic solar roof panels, Si2 uses devices called photovoltaic cells, or solar cells, to generate electricity from sunlight. These cells are very thin and made with silicon, which is a semiconductor – a material that can conduct electricity while acting like an insulator. When photons of sunlight hit a cell, it forces electrons to move from one side of the silicon wafer to the other. This flow of electrons creates a current, generating electricity that can be harnessed by an attached circuit. Si2 has over 17,000 of these cells installed across its surface. The electricity that is generated powers the plane's motors (which turn the propellers) and also charges the onboard batteries for flying at night.

Solar Impulse sought to push the boundaries, not just to set a world record but to prove that this technology could be a viable option for the future of flight. CEO, co-founder and pilot André Borschberg said in a statement, "Flying around the world is a real challenge. More than a demonstration, it's the confirmation that these technologies are truly dependable and reliable."

Borschberg and his fellow pilot Bertrand Piccard were no strangers to big challenges. Seasoned adventurer Piccard set a record when he completed the first ever non-stop balloon flight around the world in 1999, while ex-Swiss Air Force pilot Borschberg had already faced his own run-ins with danger, surviving a helicopter crash and an avalanche accident. Their circumnavigation project would face technical issues and poor flying conditions, but the combined skills and experience



Each leg of the flight was carefully planned and scheduled to make the most of optimal weather conditions

> "Within the next few decades we could be using solar-powered planes commercially"

Pilot Bertrand Piccard takes a selfie during flight in Solar Impulse 2

To infinity and beyond

Despite the breakthroughs made by the Solar Impulse team, there still remains some scepticism about how viable the technology could be for commercial planes.

There is some doubt that the crafts could sustain sufficient power to carry as many passengers as current commercial models. A Boeing 747-400 can transport over 300 passengers at a cruising speed of about 910 kilometres per hour. In contrast, the Solar Impulse is the same width but is only able to carry a single passenger at an average speed of 75 kilometres per hour.

This would also lengthen a flight from London to New York from about 7.5-hours to over three days, assuming that the solar aircraft would be at top speed for the entire transatlantic crossing.

Solar Impulse engineers are keen to find solutions to overcome the logistical challenges of solar flight

of the pilots and the Solar Impulse team ensured the journey was a success.

Unsurprisingly for a solar plane, the best time for take off is in the morning so as to make efficient use of the daylight hours. As with all flights, weather is an important factor, but it was particularly important for the Si2. While it has the wingspan of a Boeing 747 jet, it only weighs as much as a family car, so strong winds during take off or landing would easily blow it off course. In order for a flight to commence, a combination of battery power and solar energy first have to start to turn the propellers. Then with its nose titled up, the lightweight craft smoothly ascends into the air.

It rises slowly, past the turbulent jet stream at 35,000 feet (10,668 metres) up into the clouds. The pilot must skilfully dodge any dense clouds that will otherwise block the all-important sunlight from reaching the solar panels. To turn the plane, a propeller on one side of the wings speeds up. The solar panels charge the plane's batteries during the day, with the plane climbing to 28,000 feet (8,534 metres) and gliding to 5,000 feet (1,524 metres) to conserve energy at night. When it is time to land, the power to the propellers is shut off and the craft glides back down to terra firma.

The two pilots alternated between each leg of the flight. Despite the one-seater plane only being able to carry a single pilot at a time, they were never alone in the sky – on the ground, the support team were dedicated to keeping them safe. They started in Abu Dhabi before travelling eastward across Asia, crossing the Pacific, the US, the Atlantic and Europe before finally returning to Abu Dhabi. The longest journey was the Pacific crossing, completed in 117 hours and 52 minutes by André Borschberg.

So is this the future of green technology? We still have a long way to go, but it's not unrealistic to imagine that within the next few decades we could be using solar-powered planes commercially. Solar Impulse exceeded all expectations, proving just how much we can achieve already.

After landing at the final stop on this incredible journey, Bertrand Piccard addressed the crowd awaiting him: "This is not only a first in the history of aviation; it's before all a first in the history of energy. I'm sure that within ten years we'll see electric airplanes transporting 50 passengers on short- to medium-haul flights. Solar Impulse is only the beginning. Now take it further!"

Solar Impulse 2

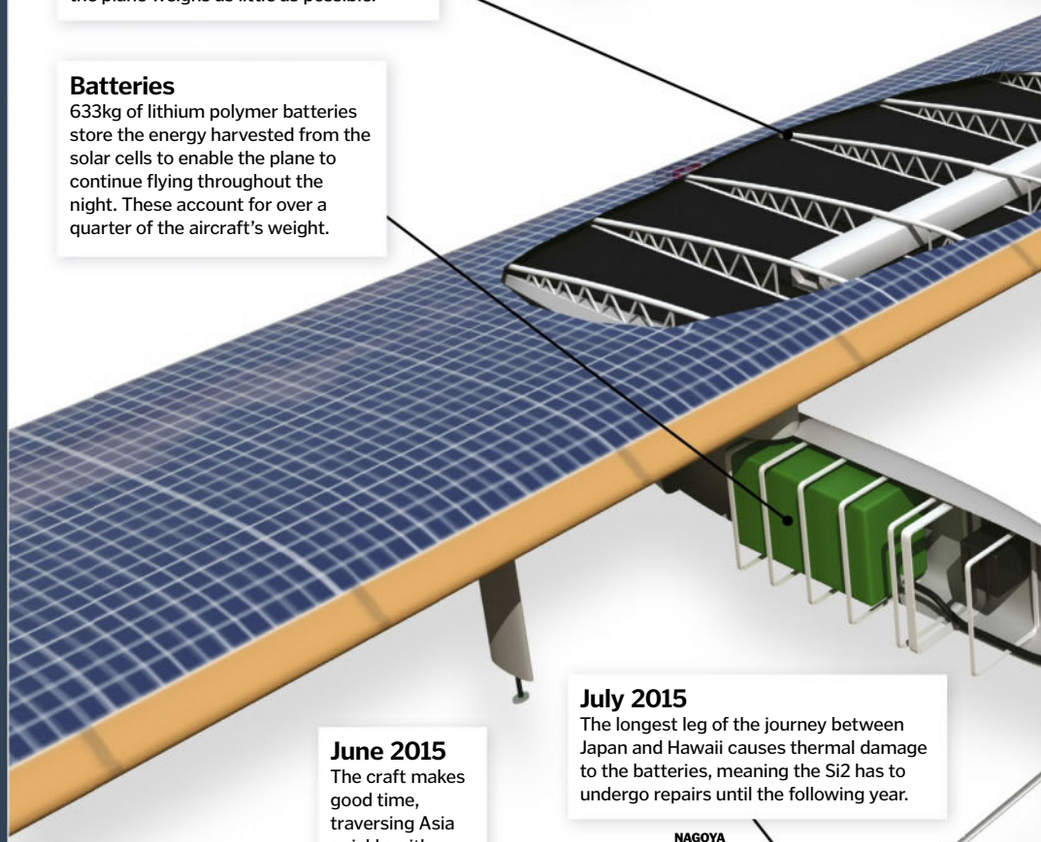
The pioneering technology that made this record-breaking journey possible

Clever composites

The plane's airframe was constructed using carbon fibre – which is three-times lighter than paper – and a honeycomb-like foam. These ultralight materials ensure the plane weighs as little as possible.

Batteries

633kg of lithium polymer batteries store the energy harvested from the solar cells to enable the plane to continue flying throughout the night. These account for over a quarter of the aircraft's weight.

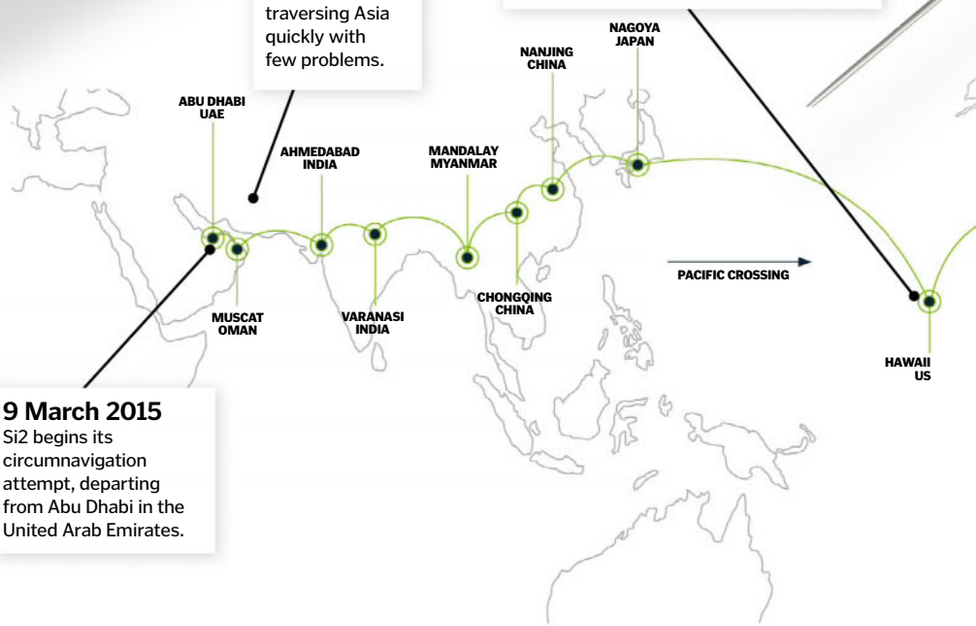


July 2015

The longest leg of the journey between Japan and Hawaii causes thermal damage to the batteries, meaning the Si2 has to undergo repairs until the following year.

June 2015

The craft makes good time, traversing Asia quickly with few problems.



9 March 2015

Si2 begins its circumnavigation attempt, departing from Abu Dhabi in the United Arab Emirates.

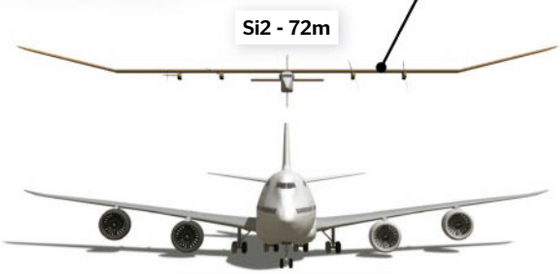
Solar cells
The 17,248 solar cells mounted on the wings can collect up to 340 kilowatt-hours of solar energy each day. This is roughly equivalent to the amount of energy stored in the fuel tank of a small car.

Compromise
The Si2 team needed to use cells that were the ideal combination of lightweight, flexible and efficient. These solar cells can convert sunlight to electricity at an efficiency of 23 per cent.

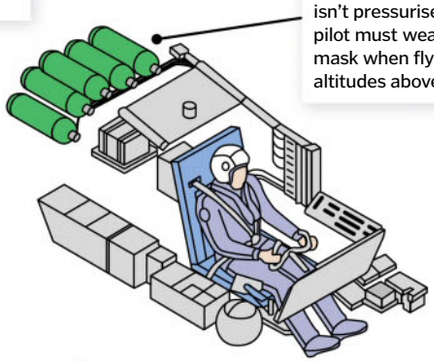
More than just the pilots, Bertrand Piccard (left) and André Borschberg (right) are the chairman and CEO respectively of Solar Impulse, and advocates of clean energy solutions

Motors
The plane's four electric motors power the propellers. Each one provides around 17.5 horsepower, which is about the same as the engine of a small motorbike.

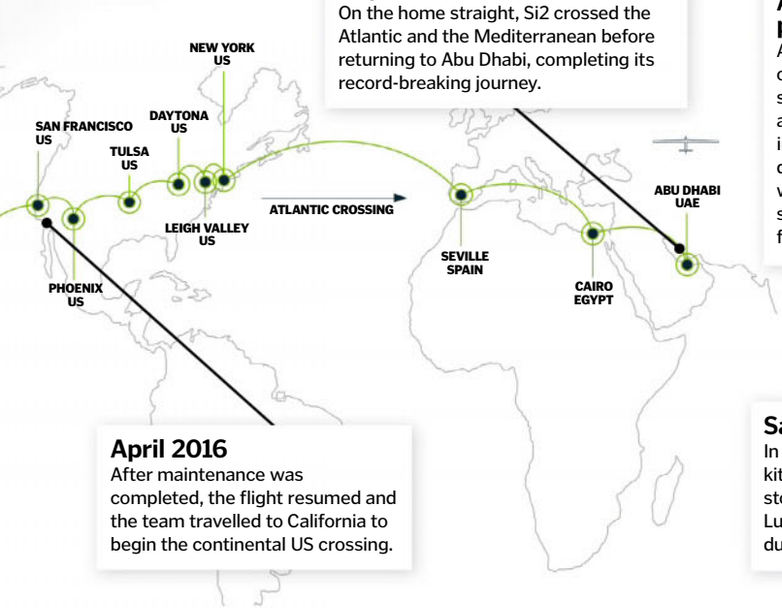
Supersized solar power
The Si2 might be super lightweight, but its wingspan rivals that of a conventional commercial airliner.



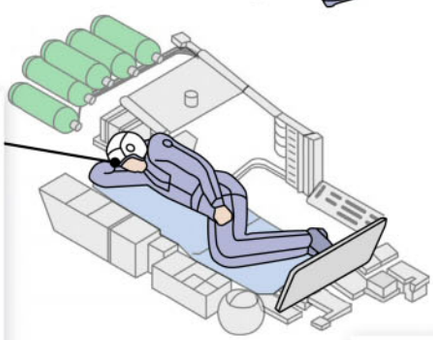
Oxygen tanks
To save weight the cockpit isn't pressurised, so the pilot must wear an oxygen mask when flying at altitudes above 3,600m.



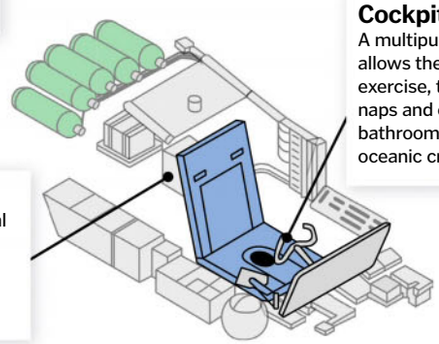
July 2016
On the home straight, Si2 crossed the Atlantic and the Mediterranean before returning to Abu Dhabi, completing its record-breaking journey.



Autopilot precautions
An autopilot system takes over while the pilot takes short breaks. If any abnormalities in the instruments' readings are detected the pilot is alerted with a vibration (which is sent via armbands on their flight suit) and an alarm.



Cockpit comfort
A multipurpose seat allows the pilot to exercise, take short naps and even go to the bathroom during long oceanic crossings.



April 2016
After maintenance was completed, the flight resumed and the team travelled to California to begin the continental US crossing.

Safety gear
In case of emergency, a survival kit, parachute and life raft are stored in the back of the seat. Luckily they weren't needed during the journey.

Creating the perfect surfboard

Find out how boards are built to make riding the waves possible

Surfboards come in a variety of shapes and sizes to suit their owner's size and riding preferences

You may automatically associate it with the Californian 'beach party' scene of the 1960s, but surfing dates back hundreds of years. It was traditionally practised by ancient Polynesian tribes, who rode waves using wooden boards. Modern boards were developed much later during the 20th century, taking the art of surfing global.

Originally, surfboards were completely made of wood; it wasn't until 1946 that the first fibreglass board tackled the waves. Entrepreneur Hobart Alter engineered the first modern surfboard in 1958 when he made boards with a polyurethane foam core and developed a fibreglass lamination process to create a board's outer shell. The fibreglass cloth used in the laminating process is made from fine fibrous strands of glass woven together. This allows boards to be extremely buoyant and flexible yet super strong.

Polyurethane is still the traditional rigid plastic foam used in board construction today. Expanded polystyrene (known as beaded foam) can also be used for board cores, but this material is incompatible with the polyester resin used to secure traditional boards.

In a world where many products are mass-produced in factories, surfboards have not yet completely followed suit. Surfboards are predominantly shaped by hand, allowing them to come in an array of shapes and styles, some of which are even unique for their users. There are around 23 million surfers worldwide, and the surfing industry is worth an estimated £5.3 billion ($7.4 billion) each year.

Making waves How to build a board step-by-step

1 Forming the core

Commonly known as the 'blank', the core of the board is mainly created from a substance called polyurethane. Poured into a heated cement mould of a board, the polyurethane becomes a dense, hard-form foam after around 25 minutes.

2 Adding stability

The now roughly shaped board is split down the vertical middle and a 'stringer' is added between the two pieces to make the board more stable. The stringer is often made of either wood or fibreglass and is glued and clamped in place.

3 Shaping the board

To create the iconic shape of a surfboard, a wooden template is traced on the blank. The board is then manually shaped by hand around the outlined stencil with the use of a sabre saw. The edges are finally sanded and cleaned down.

4 Lamination

This is when the board can be coloured or painted. Acrylic paint is applied first for design with a spray gun or an air brush. Once dry, lengths of fibreglass cloth are applied to the deck of the board before fin boxes are cut, covered in a resin and then left to harden.

5 Adding the fin

A sanding resin or filler coat is applied to fill any imperfections left behind from the lamination process. The fin is then added and secured into allocated cutouts and a small hole is drilled at the tail of the board to secure the elastic rubber cord to attach to the surfer's ankle.

6 Finishing touches

Any excess resin is now sanded off before the now-complete board is blown clean. A final gloss resin is added and left for 12 hours to dry. Once it is fully dried, the board is rubbed down, buffed and polished, then it's ready to hit the waves.

Hydraulic brakes

How does a simple press on the pedal bring a speeding car to a standstill?

Any object in motion has kinetic (movement) energy and will only stop when it loses this energy. This is the principle that brakes rely upon in order to slow down or stop machinery.

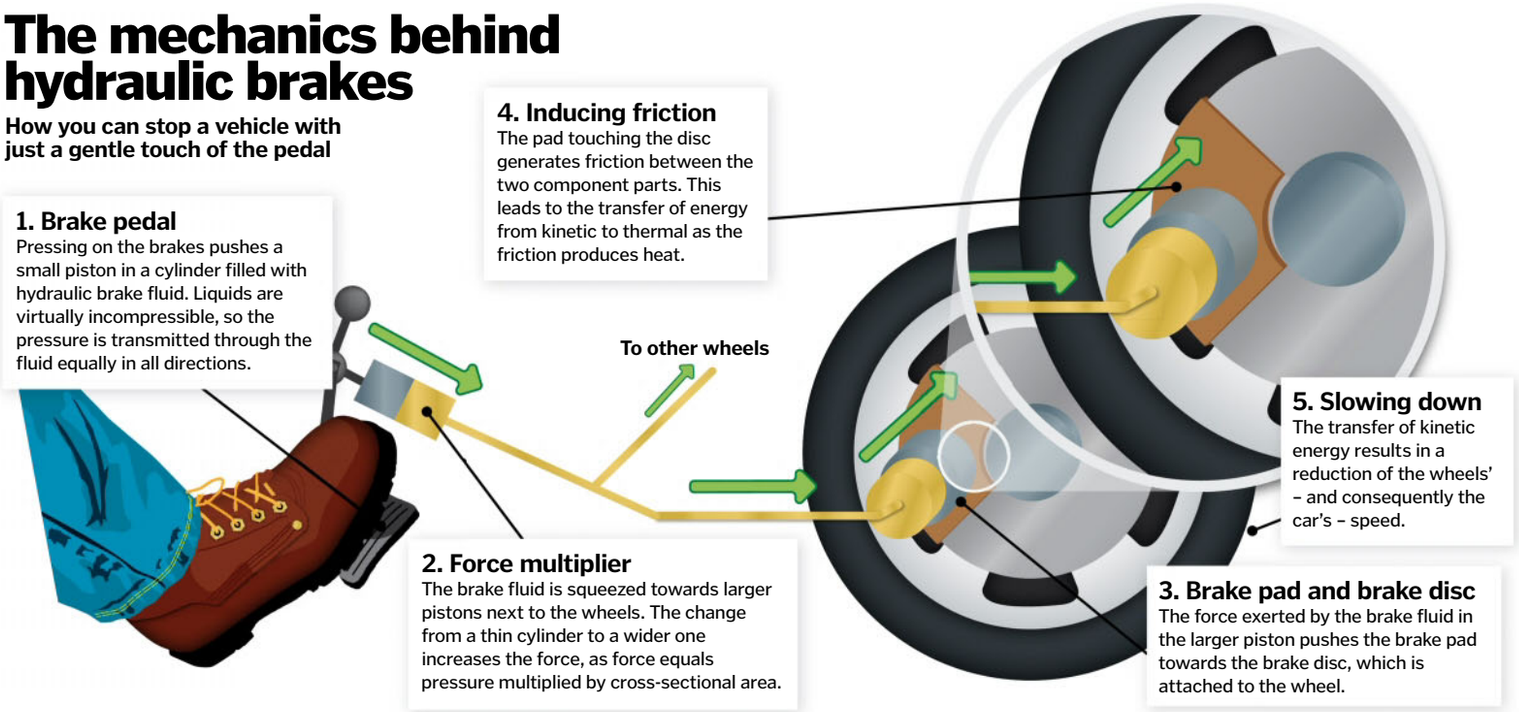
If you imagine trying to stop a car moving at 100 kilometres per hour, the force exerted by your foot alone would stand no chance at slowing the vehicle. In order to generate enough force to slow or stop a car, modern vehicles use hydraulic brakes.

These systems rely on the clever combination of fluids and different-sized cylinders to multiply the force you apply to the pedal. This means that just a small push on the pedal can be converted into a large force of the brake pads on the brake discs, quickly grinding a car to a halt as the kinetic energy is lost to friction.

Regular friction causes the brake discs and pads to wear over time, meaning that they need to be replaced frequently

The mechanics behind hydraulic brakes

How you can stop a vehicle with just a gentle touch of the pedal



1. Brake pedal
Pressing on the brakes pushes a small piston in a cylinder filled with hydraulic brake fluid. Liquids are virtually incompressible, so the pressure is transmitted through the fluid equally in all directions.

2. Force multiplier
The brake fluid is squeezed towards larger pistons next to the wheels. The change from a thin cylinder to a wider one increases the force, as force equals pressure multiplied by cross-sectional area.

3. Brake pad and brake disc
The force exerted by the brake fluid in the larger piston pushes the brake pad towards the brake disc, which is attached to the wheel.

4. Inducing friction
The pad touching the disc generates friction between the two component parts. This leads to the transfer of energy from kinetic to thermal as the friction produces heat.

5. Slowing down
The transfer of kinetic energy results in a reduction of the wheels' – and consequently the car's – speed.

Holes in plane windows

What is the purpose of these mysterious airplane pinholes?

Though it might seem dangerous to have a hole in a pressurised metal container flying at 11,000 metres, the tiny holes in airplane windows are an intentional design feature to ensure the safety of everyone onboard.

Pumping conditioned air into the cabin in order to maintain a comfortable pressure requires the windows to withstand massive pressure. The plane windows are built with three layers of acrylic, with the pane with the bleed hole sitting in the middle of the scratch pane (on the passenger side) and the outside pane exposed to the elements.

The bleed hole is there to balance the pressure between the cabin and the gap between the panes so that the cabin pressure during flight is applied only to the scratch pane. The middle pane ensures that if the outer one is damaged for any reason, there is still one pane left to protect passengers, and the plane's pressurisation system would easily compensate for the tiny hole.

The bleed holes in plane windows are an important safety feature

THE PLACEBO EFFECT

How do sugar pills and saltwater injections trick the mind into healing the body?

Sugar pills ease depression, colourful creams numb the skin and saline injections make pain melt away. The placebo effect is a powerful healer, but how does it actually work?

In the 1890s, Ivan Pavlov discovered classical conditioning. His famous experiments taught dogs to associate the sound of a bell with the arrival of food. When they heard the noise, they started to dribble in anticipation. The same thing can happen to us with medicine. We make associations based on our experiences. If people take aspirin for a headache, they start to associate the shape and taste of the tablets with pain relief. Replace the pills with a placebo and the pain will still be lessened.

Placebos, also known as 'dummy' or 'inactive' treatments, are made from inert substances like saline, starch or sugar. They look and feel like the real thing but without any of the chemical effects.

The whole experience of receiving treatment can

help us to feel better. One study gave people a painkilling cream for two days and then replaced it with a placebo. The participants had experienced the cream working, so they expected it to continue helping. Also, the tone of voice of medical staff and the information they give people about what to expect during treatment can change the way people respond. In this instance, if the staff reassured them that the new cream would work, it did. But if staff told them that the cream would increase their pain, it actually made things worse.

The appearance of medicines can also shift our expectations. We associate bold colours like red, orange and yellow with a stimulant effect and blues and greens with sedation. Change the colour of a tablet and it'll change what people expect it to do. Similarly, if a pill costs more or comes in a branded box, we expect it to outperform its cheaper or generic counterparts. Even the name of the treatment has an impact. One study found that putting the word 'placebo' on a migraine medicine called rizatriptan reduced its impact. Calling a placebo 'rizatriptan' made it work better. Not surprisingly, calling the real medicine by its proper name worked best of all.

> "Change the colour of a tablet and it'll change what people expect it to do"

The placebo effect even works with surgery. The process of cutting the skin open and stitching it back together again can help people with knee pain, and fake operations can even ease heart pain caused by angina. Nothing actually needs to happen inside the body: the sights and smells of the hospital and the procedure of an operation can trick the brain.

The first neurobiological evidence for how the placebo effect works came in the 1970s. A famous study published in 1978 in the *Lancet* looked at what happened when people received a placebo painkiller after having a tooth removed. To find out how the placebo effect worked, half of the participants were also given a drug called naloxone, which blocks the activity of natural painkillers called endorphins.

In this study, naloxone stopped the placebo tablets from working, but only when people expected the placebo to help with their pain. When we expect a tablet to kill pain, the brain makes its own painkillers.

Current evidence now suggests that this effect starts in a part of the brain called the prefrontal cortex. This region handles complex behaviours and planning. When we expect to feel better, it boosts activity in nerve pathways that extend down into the spinal cord. MRI scans have shown that the placebo effect decreases blood flow in the parts of the spinal cord that let pain signals through. The endorphins triggered by taking placebo tablets help to stop pain signals from reaching the brain.

The placebo effect works less well on people with Alzheimer's disease, who often have damage to the nerve cells in their prefrontal cortex. The effect can also be blocked by placing magnets over the scalp, interfering with nerve signals in the front of the brain.

Anxiety can also block placebo pain relief. Studies have found that simply telling people that their pain will get worse can make it worse. It can even make non-painful touching hurt, a phenomenon known as allodynia. Reading about side-effects or looking diseases up on the internet can shape what we expect to happen, and this affects the brain.

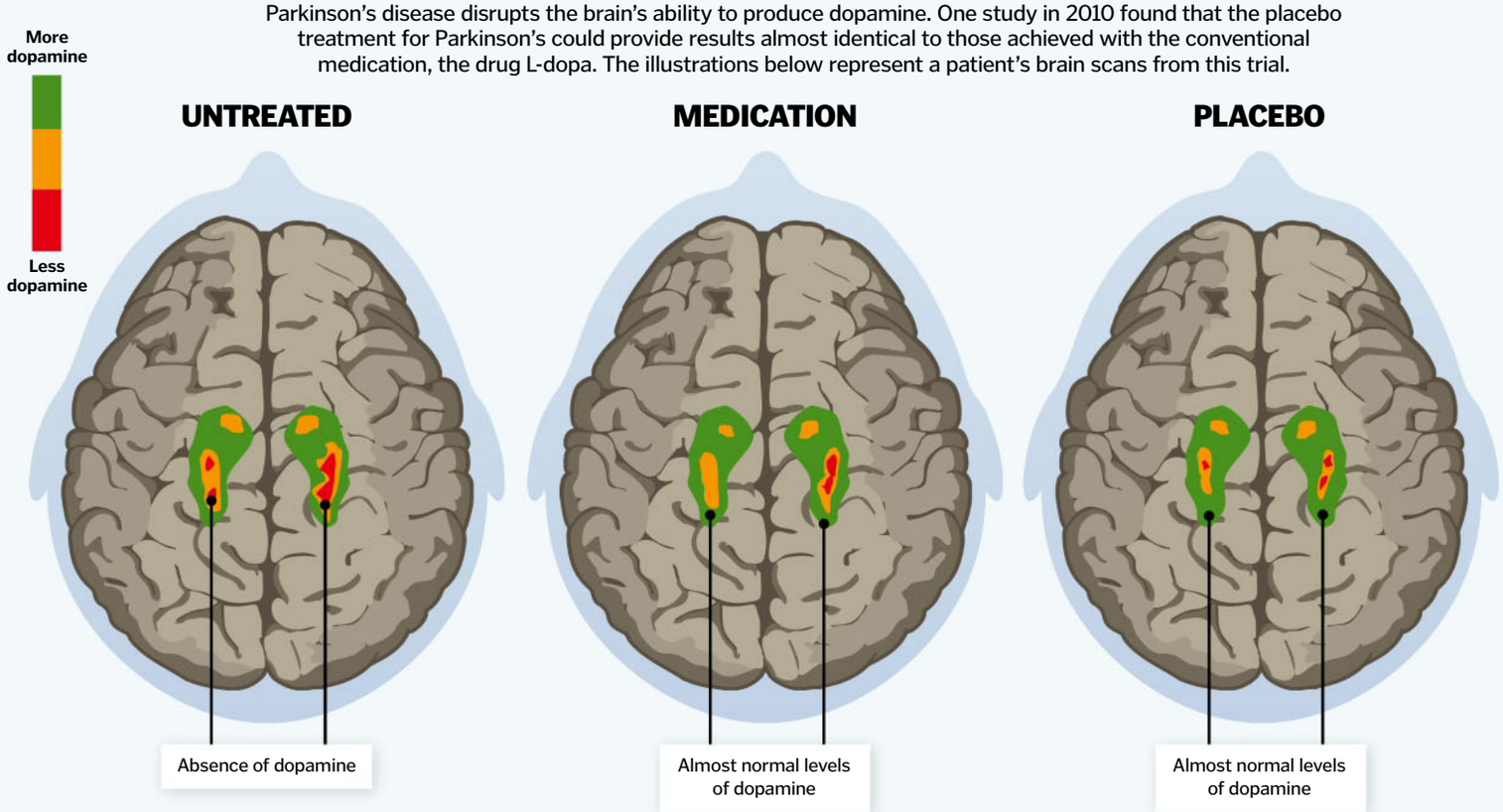
The second part of the brain's placebo system is a chemical messenger called cholecystokinin (CCK). It is produced when we are anxious. Blocking its activity with a drug called proglumide enhances the placebo effect, as does calming anxiety with the medicine diazepam.

Most of the work to understand the placebo effect has focused on pain, but dummy pills can affect other aspects of health and disease too. People with Parkinson's disease suffer damage to nerve cells in a part of the brain called the

All in the mind

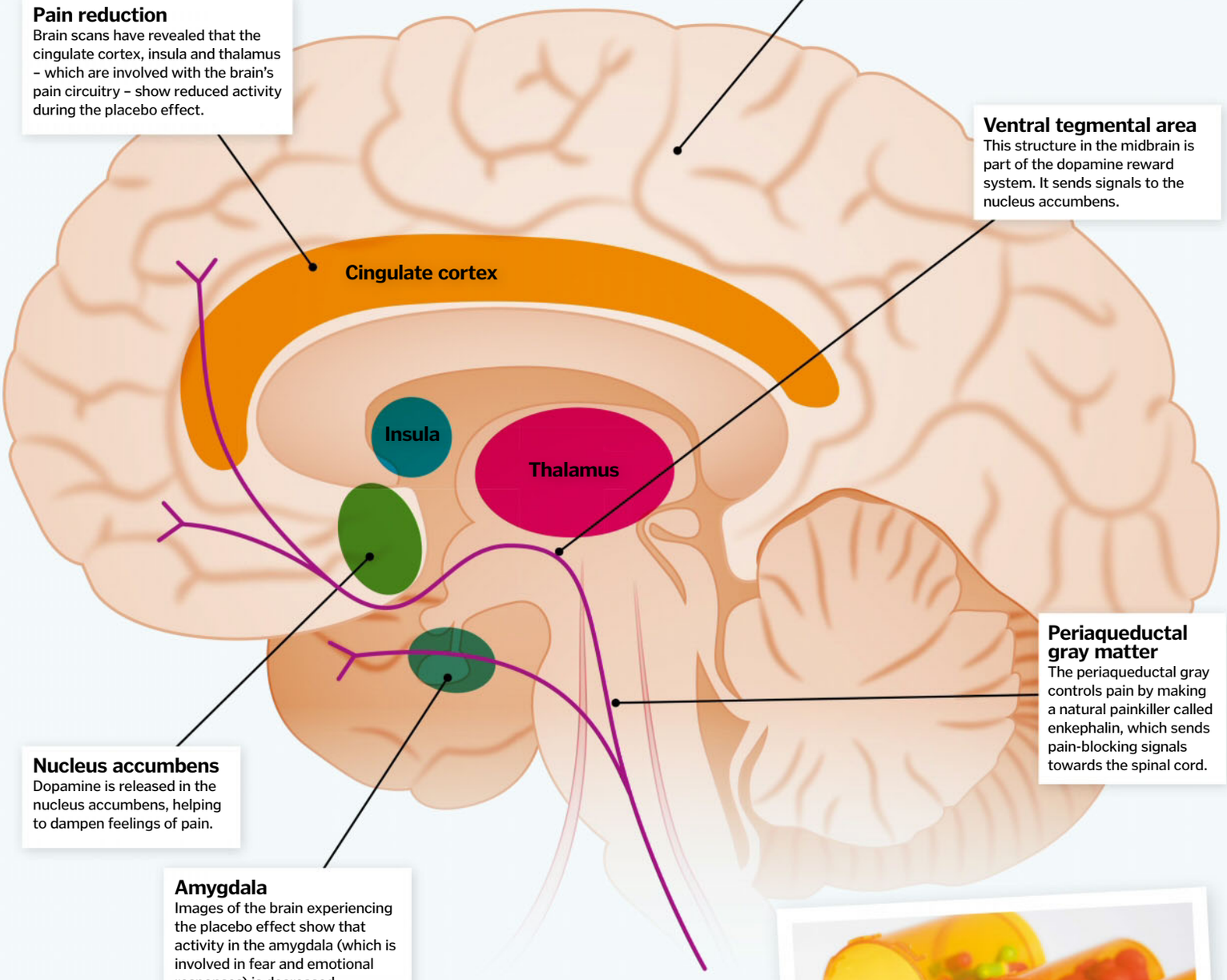
Despite its complexities, the human brain is surprisingly easy to fool

Parkinson's disease disrupts the brain's ability to produce dopamine. One study in 2010 found that the placebo treatment for Parkinson's could provide results almost identical to those achieved with the conventional medication, the drug L-dopa. The illustrations below represent a patient's brain scans from this trial.



Placebo pathways

The placebo effect depends on two separate sets of signals in the brain



Cerebral cortex
The cerebral cortex is responsible for intelligence, memory and consciousness. It sends signals to the periaqueductal gray.

Pain reduction
Brain scans have revealed that the cingulate cortex, insula and thalamus – which are involved with the brain's pain circuitry – show reduced activity during the placebo effect.

Ventral tegmental area
This structure in the midbrain is part of the dopamine reward system. It sends signals to the nucleus accumbens.

Periaqueductal gray matter
The periaqueductal gray controls pain by making a natural painkiller called enkephalin, which sends pain-blocking signals towards the spinal cord.

Nucleus accumbens
Dopamine is released in the nucleus accumbens, helping to dampen feelings of pain.

Amygdala
Images of the brain experiencing the placebo effect show that activity in the amygdala (which is involved in fear and emotional responses) is decreased.

Placebo in the brain

The science behind what really goes on inside our brain when we take a placebo

The placebo effect is all in the mind, and it's controlled by the parts of the brain that are responsible for managing anxiety, reward and pain. The cerebral cortex controls the highest brain processes, like consciousness and intelligence. The region at the front, known as the prefrontal cortex, handles complex behaviour, including our response to a placebo.

When we take a sugar pill believing it will help with pain, the prefrontal cortex passes messages to pain control neurons called the periaqueductal gray. These send natural, morphine-like painkillers into the brainstem, triggering the release of serotonin. More painkillers, known as enkephalins, then flood the spinal cord, where they block pain signals before they are able to reach the brain. At the same time dopamine streams into the brain's reward system, helping to reduce the perception of pain.

Some studies have suggested that many common drugs are just pricey placebos

substantia nigra. These damaged nerve cells stop producing dopamine, and this leads to problems with movement that worsen with time.

Placebo medicines can increase the amount of dopamine in the brains of people with Parkinson's disease. If they expect to receive real treatment and think that they will improve, dopamine levels rise on their own.

The immune system can also respond to a placebo. In 2002, the Goebel research group at the University of Duisburg-Essen in western Germany trained the immune system using a flavoured drink. They repeatedly dampened immune activity using an immunosuppressant called cyclosporin A. Each time they accompanied the treatment with the drink. After the conditioning was complete, they didn't need the drug any more. The drink was able to suppress the immune system on its own.

In 2008, they repeated the experiment with allergies. This time they gave antihistamines with the flavoured drink. Incredibly, not only did the drink make people feel better even when the antihistamines had been removed, it also reduced the activity of allergy-inducing immune cells called basophils.

Placebos in trials

The placebo effect is powerful in its own right, but to date it's been most useful as a way of testing new treatments. Studies of the placebo effect have shown that receiving a tablet and expecting it to work can be enough to make you feel better. So how do we know if a new treatment is actually working? The answer is to give half the patients the real thing and give the other half a sugar pill that looks exactly the same, then compare the two.

This works best if neither the patients nor the doctors know which treatment they are getting, a technique called 'double blinding'. This way no one can be quite sure what to expect. If the people receiving the real treatment do better than the ones on the sugar pills, you can be sure that it's not just the placebo effect at work.

Placebos are made to look and feel the same as the real treatment

The nocebo effect

While placebos can be incredibly helpful, they can also result in some unwanted side-effects

The nocebo effect is like the placebo effect but in reverse. If we think that sugar pills are the real thing then they can cause side-effects just like real medicines. It's hard to study the nocebo effect, but in 2014 Sara Planès and her colleagues at the Grenoble University Hospital in southeastern France gathered 86 studies together and reviewed the evidence.

They found that symptoms of the nocebo effect tend to be non-specific, like nausea, dizziness and headache. They also discovered that it affects women more than men, and people with depression and anxiety are particularly vulnerable. The team were also able to confirm that, just as with the placebo effect itself, the nocebo effect is partly psychological and partly neurobiological.

Conditioning can make us expect side-effects, and while chemical changes in our brains can make pain feel better, they also have the potential to make it worse.

Placebos have side-effects and can do harm as well as good

"Every time we receive medical treatment, part of the experience is psychological"

We still don't fully understand the placebo effect, but there's no escaping it. Every time we receive medical treatment, part of the experience is psychological, and medical professionals are already using this knowledge to help us get better.

There are two types of placebo. Pure placebos do nothing chemical to the body, like sugar pills or saline injections. Impure placebos are treatments that do have chemical effects but not for the condition for which they are being used. Antibiotics are an example; they treat bacterial infections but are often prescribed for flu even though it's caused by a virus.

A recent survey of UK GPs found that, though few use pure placebos, three-quarters prescribe impure placebos to their patients at least once a week. Examples can include giving people nutritional supplements, probiotics, antibiotics and alternative medicines. Alternatively, it can entail booking patients in for non-essential tests. The most simple option is just using the power of positive suggestion.

There is an ongoing debate about whether this is ethical, but similar studies in other countries have found that placebo use is widespread. The more we understand how it works, the better we will be able to harness its power.

A saline injection has a more powerful placebo effect than a sugar pill

The pharmaceutical industry will be worth around $1.5 trillion by 2022

"Reading about side-effects or looking diseases up on the internet can shape what we expect to happen, and this affects the brain"


TIME TO STEP OFF
THAT TREADMILL
With so many demands from work, home and family, there never seem to be enough hours in the day for you. Why not press pause once in a while, curl up with your favourite magazine and put a little oasis of 'you' in your day.
PRESS PAUSE
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Faraday cages

How do these conducting structures shield against electricity?

The special properties of a Faraday cage mean that anything positioned inside one is not influenced by electrical fields applied to the outside

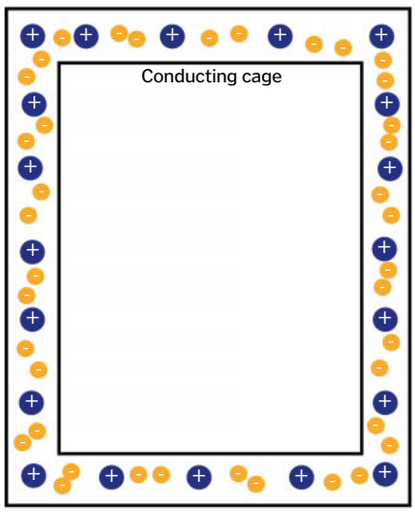
You might expect lightning hitting a car to be dangerous, but in fact if you are shut inside the vehicle you are safe. This is because an electrical charge applied to a conducting cage will travel around the edges, leaving the interior unaffected. Conducting boxes like this are called Faraday cages, named after British physicist Michael Faraday, who investigated this effect in the 19th century.

When a Faraday cage is exposed to an electric field, the negatively charged electrons on its surface move in response. This leads to one side of the cage having a negative charge and the other having a positive charge, inducing an electric field across the cage that opposes and cancels out the one being applied to the surface.

The materials and the size of the gaps on a cage can affect which wavelengths of electromagnetic radiation are blocked. This means that Faraday cages can also be used to shield against radio waves and microwaves. This makes them particularly useful for sensitive scientific experiments where electromagnetic interference is not wanted as it can skew the results.

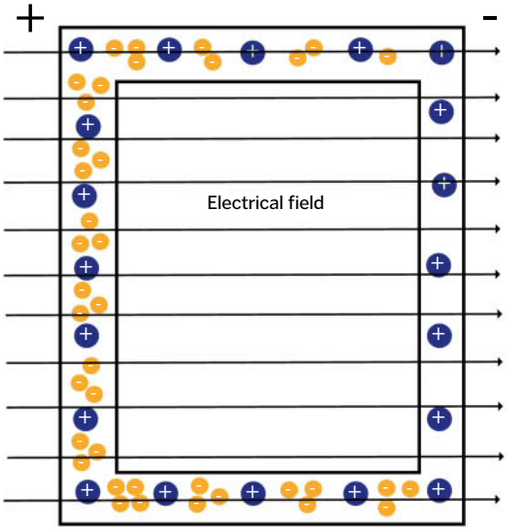
Inside a Faraday cage

How electrostatic induction helps to provide protection



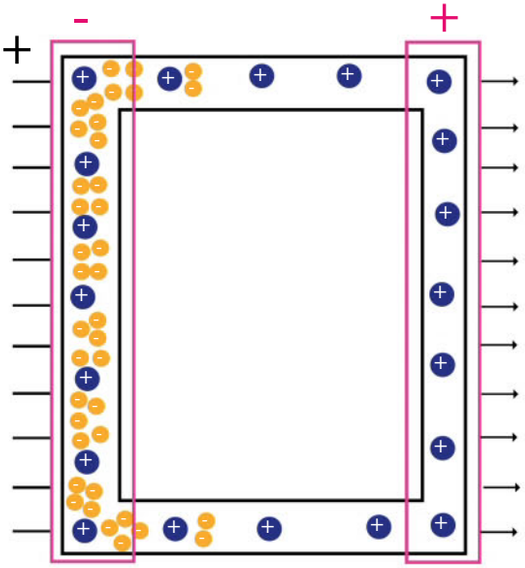
The absence of electricity

When there is no applied electrical field, a Faraday cage will have electrons equally distributed throughout the material.



Exposure to an electric field

When an electric field is applied, the charged particles within the conductive wall move. In this example the electrons move to the left, giving this part of the cage a negative charge, while the right-hand side becomes positively charged.



Balanced charges

These balanced charges create an opposing electric field that cancels out the external electric field throughout the box, therefore neutralising the inside of the cage.

What are brain banks?

These stores of organs give a whole new meaning to the phrase 'picking your brains'

The Harvard Brain and Tissue Resource Center in the US is the largest brain bank in the world, storing over 3,000 healthy and diseased brains for research

Across the world, thousands of human brains are sitting in fluid-filled lunch boxes stacked in a freezer. These are stored within brain banks that operate 24/7 to collect and store post-mortem brain and central nervous system tissue that has been donated for medical research. It sounds unpleasant, but these samples of both healthy and diseased brains are vital for research into neurological diseases, including dementia, multiple sclerosis and depression.

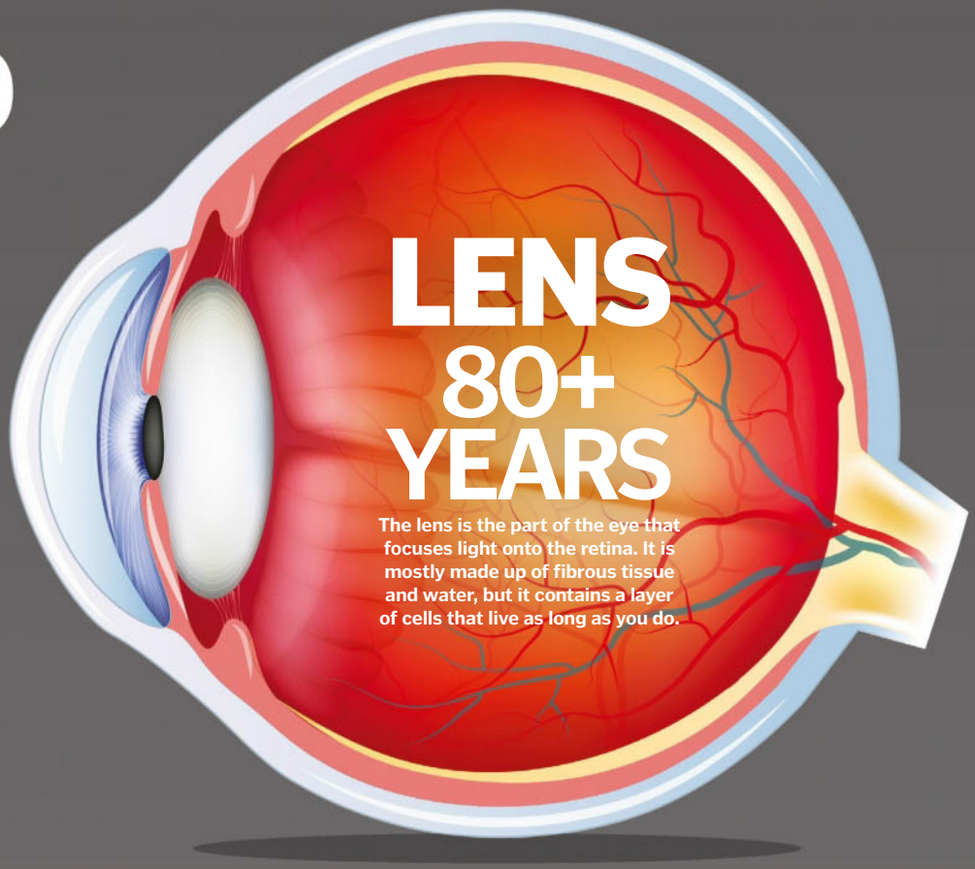
Obtaining the organs is no easy feat – the brain and brain stem must be removed from the donor within 72 hours of their death to be used in research. It is then transported to the bank as quickly as possible in an ice-packed case, where it is weighed and examined before being sliced in half. One of the hemispheres is dissected and stored in -80-degree-Celsius freezers, and the other half is stored in formalin (an aqueous solution of formaldehyde).

Researchers around the world can search for samples based on age, gender or disease, as well as brain pH range or post-mortem delay, thereby obtaining the data they need to improve our understanding of brain function and disease.

HOW OLD IS YOUR BODY?

You will make 2 million new red blood cells in the time it takes you to read this sentence

Your body contains 37.2 trillion cells. There are 86 billion neurons in your brain, 50 billion fat cells insulate your skin, and every cubic millimetre of your blood contains 4-6 million cells. But they don't live forever. Cells get old and damaged, and your body is constantly racing to replace them. Red blood cells only live for about three months; 50 million skin cells flake away every day; and sperm cells only last for three to five days. Read on to find out just how old you really are.



LENS 80+ YEARS

The lens is the part of the eye that focuses light onto the retina. It is mostly made up of fibrous tissue and water, but it contains a layer of cells that live as long as you do.

CHEEK LINING 3 hours

Studies of cheek lining cells in saliva have revealed that the lining of the mouth might renew as fast as every 2.7 hours.

STOMACH LINING 2–9 days

A thick layer of mucus protects the cells lining the stomach, but they are still replaced at least once a week.

PLATELETS 10 days

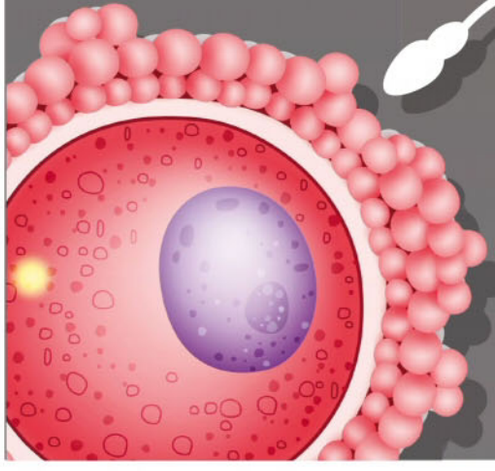
Large cells called megakaryocytes make fragments called platelets, which plug leaks in blood vessels. They only last for around ten days.

EPIDERMAL CELLS 10–30 days

There are between 18 and 23 layers of dead cells on the outside of your skin. New cells push up from below the surface every few weeks.

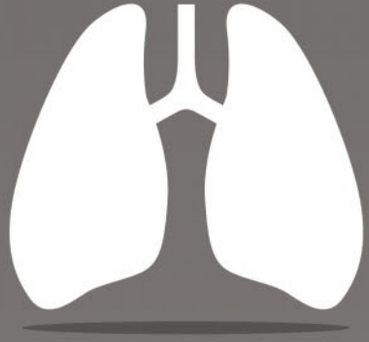
SPERM 3–5 days

Adult males produce fresh sperm constantly. These cells can survive for between three and five days as they search for an egg.



EGGS 50+ years

Females are born with all of the egg cells they will ever have, but they are no longer released after the menopause.

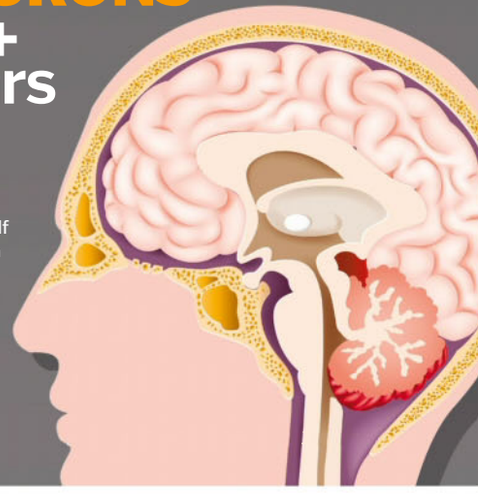


LUNG LINING 8 days

The delicate lining of the lungs is just one cell thick and lasts just over a week.

CEREBRAL NEURONS 80+ years

You might have heard that the whole body renews itself every seven years, but brain cells last as long as we do.



LARGE INTESTINAL LINING
3–4 days

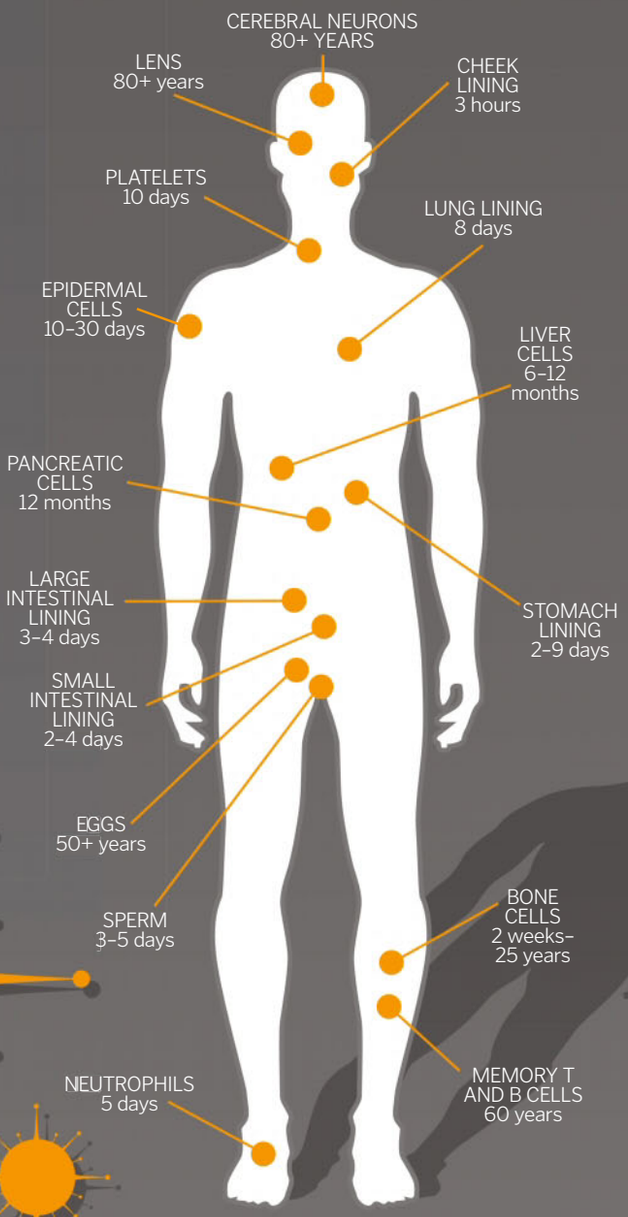
The lining of the intestine is one of the fastest-renewing tissues in the body. Its job is to remove water from digested food, and it regrows every three or four days.

SMALL INTESTINAL LINING
2–4 days

The lining of the small intestine absorbs nutrients from digested food. It gets replaced every two to four days.

THE CELLS THAT LINE THE SMALL INTESTINE ARE SOME OF THE FASTEST-DIVIDING CELLS IN THE BODY

AN OVERVIEW TO YOUR BODY'S AGE



MEMORY T AND B CELLS
60 years

T and B cells are part of the immune system. After they clear an infection they stick around for years in case the same pathogen should come back.

PANCREATIC CELLS
12 MONTHS

Beta cells in the pancreas make insulin. Their exact lifespan is still unknown, but scientists think that they live for over a year.

LIVER CELLS
6–12 MONTHS

Liver cells normally last for 200–300 days, but they can divide rapidly if needed. Remove 75 per cent of the liver and it will grow back.

BONE CELLS
2 WEEKS–25 YEARS

Bone-absorbing osteoclasts live for two weeks, bone-making osteoblasts for three months and bone-sustaining osteocytes for up to 25 years.

NEUTROPHILS
5 DAYS

White blood cells called neutrophils are first on the scene when an infection strikes. They live for less than a week.

Hyperthermia vs hypothermia

What happens to the human body when the temperature is too high or too low?

The human body operates best at a temperature of around 37 degrees Celsius. We can tolerate a change of a few degrees in either direction, but any more than that and things start to go wrong.

Once body temperature drops below 35 degrees Celsius, mild hypothermia kicks in. To conserve heat, the body diverts blood away from the skin and hairs stand on end. The muscles contract and relax involuntarily, burning fuel to generate warmth. The colder the body gets, the more it starts to slow down. Nerve signals become sluggish, speech gets slurred and confusion starts to set in.

If the core temperature drops below 32 degrees Celsius, the situation becomes critical and medical attention is needed. At this point, shivering stops and the person may pass out. Below 30 degrees Celsius, the body loses its ability to warm itself up again, and this is often fatal.

The opposite of hypothermia is hyperthermia. The body has built-in mechanisms to lose heat, but sometimes it's too warm for them to work properly. If the body can't get rid of excess heat, core temperature starts to rise.

Sponging the head and neck can help to cool people down

Confusion
The cold affects cognitive function, making people feel drowsy and confused.

Altered breathing
At first, breathing speeds up, but as hypothermia progresses, both heart rate and breathing rate will slow down.

Dizziness
The combination of dilated blood vessels and fluid loss affects blood pressure, causing dizziness.

Thirst
Water is lost to sweating, lowering the amount of fluid in the blood and triggering thirst.

Sweating
Sweating cools the skin as water evaporates, which also removes some of the excess heat.

Too hot or too cold

What are the signs of hyperthermia and hypothermia?

When sweating isn't enough to lower body temperature, it can lead to dizziness and nausea. The loss of fluid triggers thirst and headaches. At the same time blood vessels dilate, bringing hot blood to the skin, but as the amount of fluid in the system drops, so too does blood pressure. This can cause dizziness and even fainting.

If the temperature climbs to over 40 degrees Celsius, molecules become misshapen and can no longer do their jobs properly, and cells start to die. Untreated, hyperthermia can lead to multiple organ failure.

Thankfully, the body has a built-in thermostat that normally keeps the temperature constant.

"If the core temperature drops below 32°C the situation becomes critical"

Our skin turns pale when we are cold because our blood vessels constrict

Shivering
An automatic shivering mechanism helps to generate extra heat by contracting and relaxing the muscles.

Pale skin
The blood vessels in the skin constrict, diverting blood to the core of the body and helping to conserve heat.

Dilated blood vessels
The blood vessels dilate, bringing warm blood to the surface of the skin.

Getting back to normal

Cooling someone with hyperthermia can be as simple as getting them out of their environment. This might be seeking shade on a sunny day or using fans and dehumidifiers to lower the temperature of the room. Sponging the head, neck and torso with water and offering people cold drinks can also help. For serious cases, hospital treatment can involve flushing the stomach with ice water, pumping cool air into the lungs or cooling the blood by passing it through a dialysis machine.

For hypothermia, dry blankets, warm drinks and energy-rich foods (only if they can swallow normally) can restore normal temperature, but hot baths, alcohol and rubbing the skin can be dangerous. Levels of a hormone called vasopressin drop when we are cold, leading to the production of lots of diluted urine. This can lower the amount of blood in circulation. If the blood vessels in the skin dilate too fast, the sudden drop in blood pressure can stop the heart beating.

Hypo- and hyperthermia can become very serious if they are not treated quickly. Always seek medical advice immediately if you think someone might be suffering from either condition.

Severe hyperthermia can be treated with dialysis to cool the blood

DID YOU KNOW? *While a fever is a rise in body temperature caused by your body, hyperthermia is a rise your body can't control*

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How microwaves cook food

Find out how these convenient kitchen gadgets heat food in just a few minutes

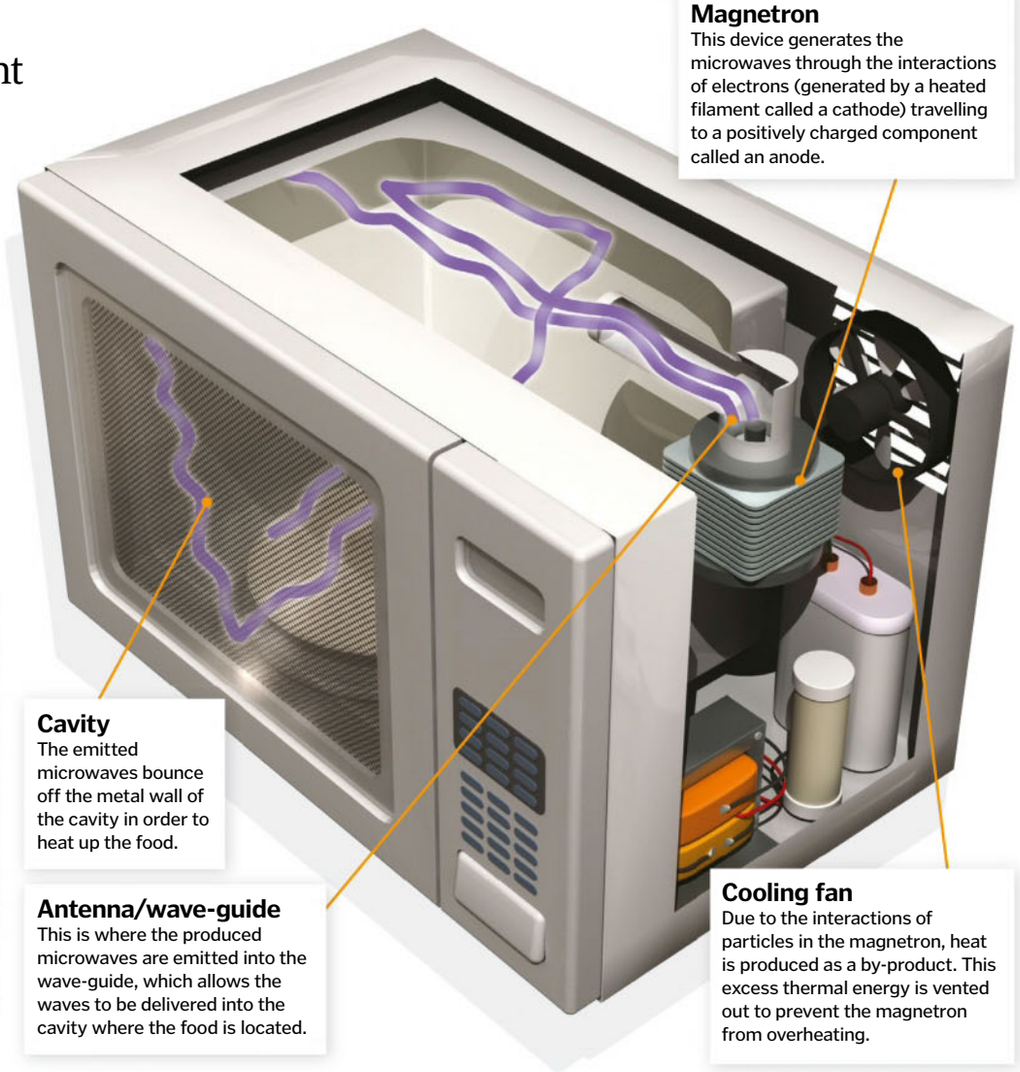
Whether it's warming up last night's takeaway or cooking a ready meal for one, microwaves are truly versatile in their cooking ability. The secret to their culinary capabilities lies in their relationship with the water, fat and sugary molecules in food.

Microwaves emitted into the metal box vibrate the water molecules in your soup, for example, at such a high rate that it generates heat energy. By heating up these molecules it in turn heats up the surrounding molecules that make up your meal and 'ping!', it's done.

In 2016, the global value of the ready meal industry was calculated as just over $194 billion (approx £138 billion)

Inside the oven

How are microwaves generated within this box and used to cook food?

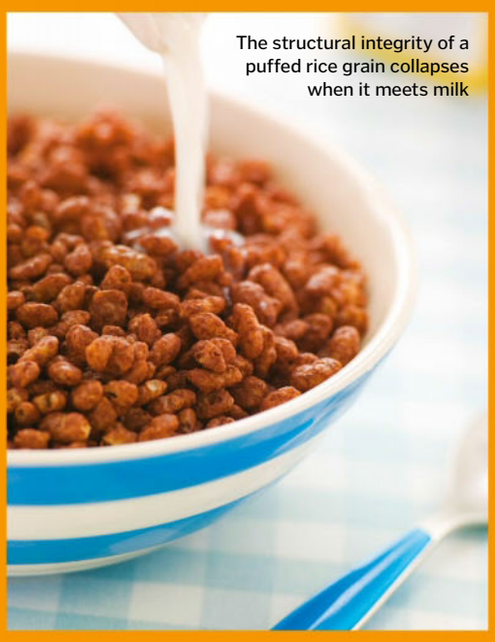


Magnetron
This device generates the microwaves through the interactions of electrons (generated by a heated filament called a cathode) travelling to a positively charged component called an anode.

Cavity
The emitted microwaves bounce off the metal wall of the cavity in order to heat up the food.

Antenna/wave-guide
This is where the produced microwaves are emitted into the wave-guide, which allows the waves to be delivered into the cavity where the food is located.

Cooling fan
Due to the interactions of particles in the magnetron, heat is produced as a by-product. This excess thermal energy is vented out to prevent the magnetron from overheating.



The structural integrity of a puffed rice grain collapses when it meets milk

The science of snap, crackle & pop

How does milk turn your breakfast cereal into a veritable pop concert?

It's an iconic crackling sound, and at some stage we have all held our ears up to a bowl to listen to the crispy grains singing in milk. Crispy rice cereal is exactly what the name suggests; pieces of crisped or puffed rice. As rice grains are cooked in the process in order to produce puffed cereal, water escapes the grain, much in the same way as when popcorn is heated up. The result is a piece of puffed rice with a hollow centre and a series of holes on its surface, and it is this transformation in the structure of the rice that results in each mini bang in your breakfast bowl.

Unlike the rigid structure of a fibre-filled bran flake, puffed rice allows liquid – in this case the milk you pour over your cereal – to enter the inside of the grain. This forces the residing air out of its hollow interior, causing the walls of the grain to shatter and thereby create a symphony of pops, bangs and crackles. However, puffed rice isn't the only cereal to make a sound; you'll just have to keep an ear out for the others.

MODERN-DAY DINOSAURS

Discover the animals that lived to tell the tale of a mass extinction

> "A piece of space rock fell from the sky, changing the course of history forever"

With lush green jungles and the sweet scent of the first flowering plants filling the air, the Cretaceous period saw the planet at its prehistoric prime. Giants dominated the land, sea and skies up until around 66 million years ago, thriving in the abundance of life occupying Earth. That was of course until a huge piece of space rock fell from the sky, obliterating the dinosaurs and changing the course of history forever. But, some species managed to cling on to life and avoid extinction.

DEFINING THE DINOSAURS

Dinosaurs are a group of reptiles that evolved from a class of creatures called archosaurs ('ruling reptiles'). The archosaurs evolved around 250 million years ago, eventually dividing into two different lineages: one evolutionary branch gave rise to the ancestors of crocodiles (Pseudosuchia) while the other led to the evolution of pterosaurs, dinosaurs, and eventually birds (Ornithosuchia). All these creatures – even the birds and crocodiles alive today – share a common archosaur ancestor.

One of the first dinosaurs to take its steps some 230 million years ago during the Triassic period was a small, speedy, two-legged omnivorous dinosaur called the eoraptor. 15 million years later, any animal on Earth with a length of one metre or more was a dinosaur. These beasts evolved to fill lots of different ecological niches, from towering titanosaurs to miniature microraptors. Dinosaurs were widespread on our planet, dominating the land for over 160 million years before a cataclysmic event wiped out 75 per cent of all life on Earth.

THE END OF AN ERA

The exact explanation for the demise of the dinosaurs had been debated for many years until a huge crater was discovered in Chicxulub, Mexico, in 1991, a finding that finally shed some light on the truth behind the violent end of these ancient titans.

Now known as the Cretaceous-Paleogene (K-Pg) extinction event, the dinosaurs were

Discover dinosaurs live

Evolutionary biologist, primatologist and broadcaster Dr Ben Garrod is telling the tale of the deadliest predators that ever roamed the planet – and those still walking among us – in his returning hit live show, *So You Think You Know About Dinosaurs*.

"With palaeontology the information changes every week, every day, but it's the same sort of information that I would teach to undergraduates and to six or twelve year olds. There is no reason why they can't have that sort of content as long as it is engaging and accessible, and that is exactly what science should be — it should be fun and entertaining. The show is a combination of a big PowerPoint, with videos and slides and different puzzles, but we are also talking about things like synapsids and diapsids and pentadactyl limbs."

Diving into the prehistoric world of the land giants, Garrod kicks off his show this March at the Theatre Severn in Shrewbury. "It's fun and engaging, but nothing is dumbed down. The kids don't go five minutes without laughing or joking or asking a question, but it's guaranteed they will learn something. It's fun for everyone."

wiped out following the impact of a ten-kilometre-wide asteroid colliding with Earth at over 64,000 kilometres per hour. The explosive power of the impact gauged a 180-kilometre-wide hole in the Earth's surface and killed 80 per cent of the plants and animals living within its vicinity. Yet despite the incredible power of this event, the impact itself was not the sole cause of the global extinction: the atmospheric aftermath also played a key part.

Due to its sheer scale and size, the asteroid vaporised on impact, raining red-hot ash and creating a vast cloud of particulate pollution. Evolutionary biologist and broadcaster Dr Ben Garrod describes the devastation. "The area of impact was full of gypsum, and when gypsum is vaporised it makes this horrific acidic concoction that then falls as acid rain. This huge cloud of toxic gas, along with molten ash, was thrown into the atmosphere, creating a pizza oven effect, resulting in the Earth baking for months."

This fiery rain increased the Earth's global temperature to levels fatal to large reptiles with nowhere to go. However, it was the darkening of the sky that lead to the ultimate destruction of the dinosaurs. Acting like a curtain across Earth, this atmospheric debris shrouded the surface from sunlight. By removing light, plants could no longer photosynthesise properly. Since plants are an integral part of every food chain, without them a chain reaction of starvation swiftly followed. It was only those that could rely on alternative food sources that would live to witness the dawn of a new era.

SURVIVAL OF THE FITTEST

It may have caused the death of the dinosaurs on a global scale, but not all species were wiped out in this devastating mass extinction. To escape the intense heat of the falling ash and the cold global winter that followed, many of those that could dig or dive lived to see another day. In fact,

Crocodiles and alligators gradually shrank in order to survive the mass extinction

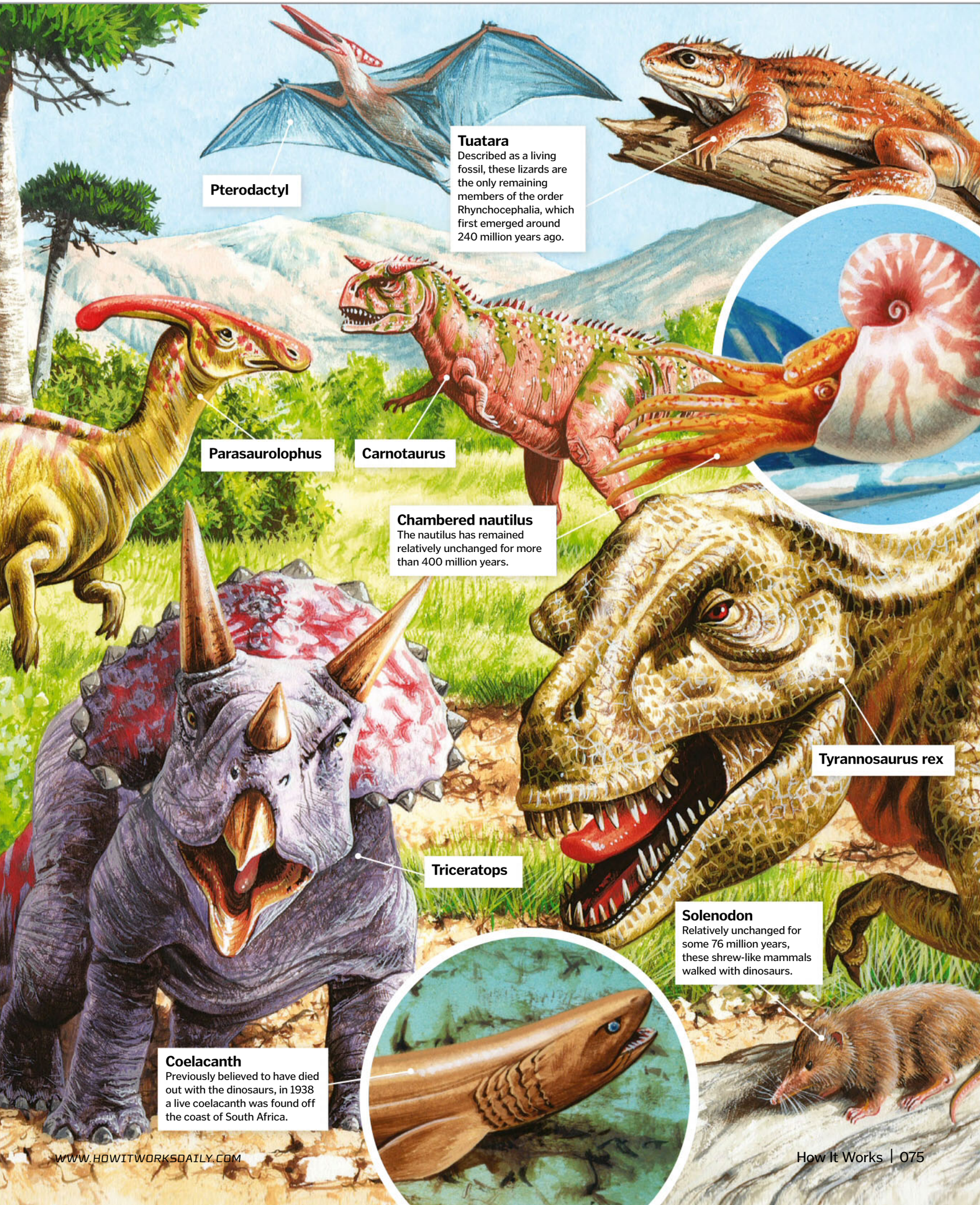
DINOSAUR NEIGHBOURS

Meet the modern creatures that descend from those that walked with dinosaurs

Snakes
Surviving the mass extinction, fossil evidence of snakes has been dated back 150 million years.

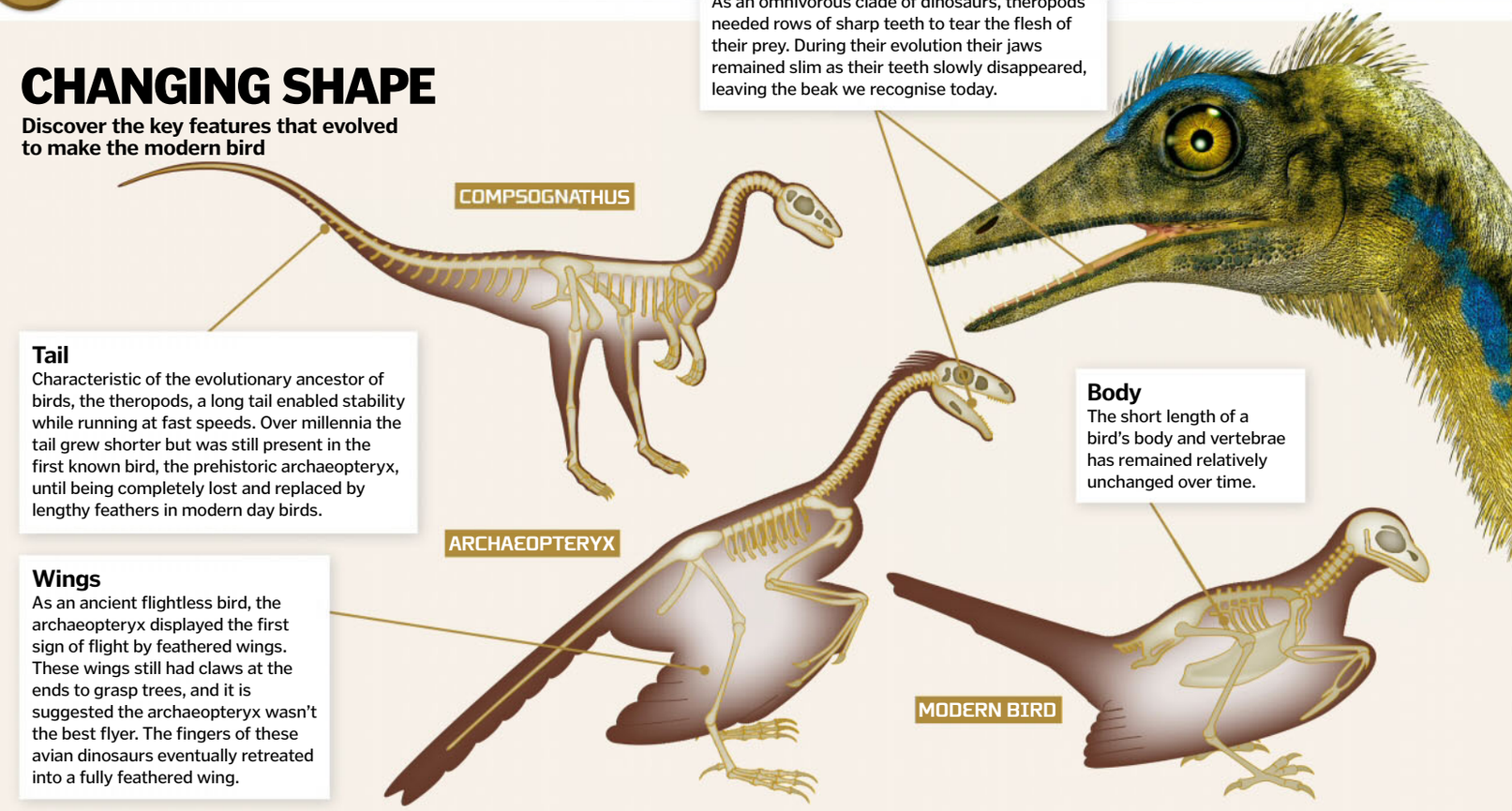
Bees
Experiencing a mass extinction of their own, bees managed to claw their way back from decline.

"Crocodiles are perfectly adapted to their environment"


Pterodactyl
Tuatara
Described as a living fossil, these lizards are the only remaining members of the order Rhynchocephalia, which first emerged around 240 million years ago.
Parasaurolophus
Carnotaurus
Chambered nautilus
The nautilus has remained relatively unchanged for more than 400 million years.
Tyrannosaurus rex
Triceratops
Solenodon
Relatively unchanged for some 76 million years, these shrew-like mammals walked with dinosaurs.
Coelacanth
Previously believed to have died out with the dinosaurs, in 1938 a live coelacanth was found off the coast of South Africa.

CHANGING SHAPE

Discover the key features that evolved to make the modern bird



Teeth
As an omnivorous clade of dinosaurs, theropods needed rows of sharp teeth to tear the flesh of their prey. During their evolution their jaws remained slim as their teeth slowly disappeared, leaving the beak we recognise today.

Tail
Characteristic of the evolutionary ancestor of birds, the theropods, a long tail enabled stability while running at fast speeds. Over millennia the tail grew shorter but was still present in the first known bird, the prehistoric archaeopteryx, until being completely lost and replaced by lengthy feathers in modern day birds.

Body
The short length of a bird's body and vertebrae has remained relatively unchanged over time.

Wings
As an ancient flightless bird, the archaeopteryx displayed the first sign of flight by feathered wings. These wings still had claws at the ends to grasp trees, and it is suggested the archaeopteryx wasn't the best flyer. The fingers of these avian dinosaurs eventually retreated into a fully feathered wing.

it was the death of the dinosaurs that gave rise to the age of mammals.

Having sheltered from the impact below ground, the first true mammals soon emerged; creatures that could sustain themselves on invertebrates and plants. Arguably the most peculiar mammal members that survived the mass extinction were the egg-laying mammals: the platypus and echidna.

Those that took to the depths of the oceans also fared well, feasting on those relatively unaffected by the climatic change occurring above the waves. Sharks, for example, had hunted the oceans long before dinosaurs had taken their first steps and have lasted long after their departure. But there is one common feature that links all those that survived the catastrophe: their size.

"Size is definitely a big factor, anything bigger than the ten to 20 kilogram mark was gone. At the moment there is no evidence for anything even cow-size that survived. Most dinosaurs were relatively on the larger side. [On land] a lot of other reptiles, birds at the time, even quite a few mammals survived, but nothing other than that," explains Dr Garrod.

The ability to survive above and below the water enabled prehistoric crocodiles and alligators to gain the upper hand. Thick scales, a long jaw housing razor-sharp teeth and a substantial tail proved a useful arsenal in the quest for survival.

"Crocodiles are perfectly adapted to their environment; they can deal with really hostile situations, such as environments lacking in oxygen. The order Crocodilia evolved separately to dinosaurs. They are true reptiles and evolved 86-85 million years ago. So they were quite new on the scene," explains Dr Garrod.

As exotherms, crocodiles have been to seen to enter a stasis-like state to ensure their survival; a beneficial quality when dealing with a global climatic change, a quality the dinosaurs unfortunately did not possess. Size, as it did for any of the other species that survived the asteroid impact, played a massive role in the longevity of the crocodiles. Dwarf crocodiles living today are about the same size as their ancestors that escaped the brink of extinction.

Charles Darwin once wrote, "It is not the strongest of the species that survives, nor the most intelligent that survives. It is the one that is

> *"Birds have lost tooth and nail to maintain their stronghold on Earth"*

Theropods, meaning 'beast-footed', were the only large land carnivores for 100 million years

most adaptable to change." With the planet labouring under such harsh conditions, only those able to adapt to their new environment survived and evolved into the species we see today. There is one group of animals in particular that not only survived the mass extinction but thrived after it.

FEATHERED FAMILY

As direct descendants of dinosaurs still roaming the planet, birds have lost tooth and nail to maintain their stronghold on Earth. The first signs of a feathered future for dinosaurs began around 245 million years ago in the form of a group of dinosaurs called the theropods. This collection of reptiles balanced themselves on two hind legs with the help of a long tail, while two short forearms enabled them to grasp and pull apart the flesh of their prey. The foot of a theropod is the first visible similarity to a current-day bird, with three extended clawed toes protruding in front of a smaller back toe. Feathers soon followed in non-avian theropods such as the oviraptorosaur, but these dinosaurs still had not harnessed the power of flight.

Over millennia these dinosaurs steadily evolved into the first known winged dinosaur, the archaeopteryx, taking to the skies around 150 million years ago. During the next 80 or so million years, this clade of dinosaurs became smaller and smaller, losing the claws at the tips of their wings and replacing their teeth-laden jaws with beaks, and it was this transformation that was key to surviving the mass extinction.

Prehistoric birds similar in appearance to the ones we know today began to develop, such as the crow-like confuciusornis. Beaks and wings were the real saving grace for birds following the extinction event. As plant resources were declining, a lack of teeth enabled them to access seed and invertebrate food resources in a world where food was scarce. Their ability to fly gave them a distinct advantage over less fortunate land-dwelling animals, enabling them to reach areas of refuge.

"There must have been pockets of little oases around the world. Havens where nothing was touched, such as gorges or valleys. We don't know where they are yet, but there could be two or three little places potentially, or maybe dozens of places that were untouched, beautiful, lush, tropical places," says Dr Garrod.

Without the now-deceased carnivorous giants hunting them, or their herbivorous counterparts consuming their weight in vegetation, birds and other small animals were able to sustain themselves, thus birthing the lineage of the living fossils we see today.

Birds are the only living descendants of the dinosaurs

The K-Pg extinction is one of five mass extinctions to date

WING EVOLUTION

Based on the fossils found through the ages, palaeontologists have pieced together some important anatomical details that can help us reveal how wings developed from limbs*

*The illustrations below are examples of different stages of wing development, but don't represent a direct progression

Sinosauropteryx | **Unenlagia** | **Archaeopteryx** | **Eoalulavis** | **Modern birds**

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The Porcelain Tower of Nanjing

The construction, destruction and revival of a medieval wonder

In early 15th-century China, the Yongle Emperor of the Ming dynasty ordered the construction of a towering monument to honour his mother. The Porcelain Tower was a grand pagoda built in the city of Nanjing – the imperial capital at the time – as part of the grand Bao'en Buddhist Temple complex.

The tower was constructed from white porcelain bricks, which would have glistened in the sunlight, and adorned with vibrant glazed designs of animals, flowers and landscapes in greens, yellows and browns. Historians studying the remnants suggest that the glazed porcelain bricks were made by highly skilled workers, but sadly the methods used to make them have been lost to history.

Some of the largest bricks were more than 50 centimetres thick and weighed as much as 150 kilograms each, with the coloured glazes staying bright for centures. Nowadays, workers trying to replicate these porcelain slabs struggle to make anything larger than five centimetres thick and their colours fade after just a decade.

The tower was widely regarded as the most beautiful pagoda in China, and it became renowned as one of the seven wonders of the medieval world, featuring in the records of westerners who travelled to the region. This porcelain pagoda was also one of the tallest buildings in the area (possibly in all of China) until it was almost completely reduced to rubble during the Taiping Rebellion in 1856.

Rebuilding the wonder

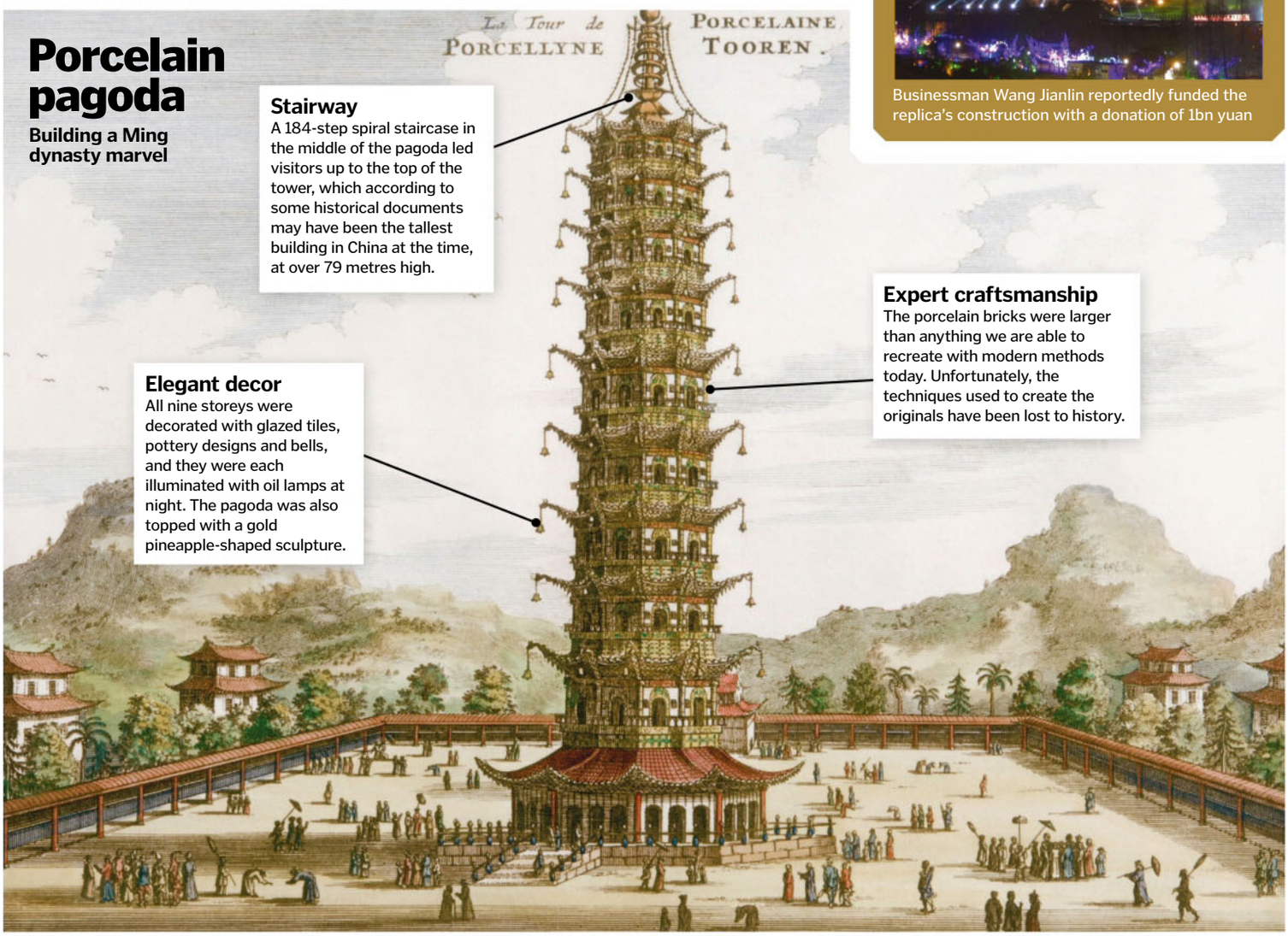
Today, the old and new stand side by side at the Porcelain Tower Heritage Park. The reconstructed tower (made from steel girders and glass rather than porcelain) overlooks the museum housing the original blocks of the Nanjing Tower door.

The new high-tech replica provides an interactive experience, as visitors are encouraged to use a smartphone to scan QR codes for more information about the site. The incredible interior of the new building immortalises the historical and cultural significance of the original medieval tower in mesmerising displays of sound and light, including a room of thousands of light bulbs that change colour. The new tower also offers 360-degree views of the city as it overlooks a landscape of rivers and architecture.

Businessman Wang Jianlin reportedly funded the replica's construction with a donation of 1bn yuan

Porcelain pagoda

Building a Ming dynasty marvel



Stairway

A 184-step spiral staircase in the middle of the pagoda led visitors up to the top of the tower, which according to some historical documents may have been the tallest building in China at the time, at over 79 metres high.

Expert craftsmanship

The porcelain bricks were larger than anything we are able to recreate with modern methods today. Unfortunately, the techniques used to create the originals have been lost to history.

Elegant decor

All nine storeys were decorated with glazed tiles, pottery designs and bells, and they were each illuminated with oil lamps at night. The pagoda was also topped with a gold pineapple-shaped sculpture.

Florence Cathedral

This iconic building is the result of centuries of Italian artistry and a mind-boggling architectural achievement

In 1294 the leaders of Florence decided to build a grand cathedral, not only to reflect the huge success and prestige of the city but also to compete with its rivals, such as Milan and Venice. Work began two years later around the existing church of Santa Reparata. The new cathedral was to be called Santa Maria del Fiore (Saint Mary of the Flower), echoing the traditional name of Florence: Fiorenza. Today it is commonly referred to simply as 'Il Duomo'.

One of the first items on the Florentine council's wish list was a large bell tower, which was designed by master builder Giotto di Bondone. At nearly 85 metres tall, this grand design dominated the Florentine skyline when it was completed in 1359 and dwarfed a certain tower in neighbouring Pisa (which stands at 57 metres tall). Its seven huge bells weigh over 10 tons – more than enough to wake sleepy Florentines for mass. Unfortunately, Giotto never saw the completion of his vision as he died just three years into the project, leaving his assistant Andrea Pisano to continue his work.

Yet another ambitious architect by the name of Francesco Talenti took charge of the project after Pisano's death in 1348 and set about enlarging the original plans. The new nave (the central walkway), along with its vaulting ceiling and aisles, were completed in 1380. By this time the new Gothic-style walls had entirely enveloped the old Santa Reparata, and the old building was finally demolished.

In the 15th century, Florence's most talented sculptors were commissioned to carve out marble statues to decorate the exterior structure, depicting biblical figures as well as the city's most influential citizens. At the time of its completion the cathedral was the largest in Europe. Today it is part of a UNESCO World Heritage Site, embodying centuries of artistic and architectural eras.

The emblem 'OPA' on the cathedral floor represents Opera del Duomo, the organisation behind its construction

"By the time of its completion the cathedral was the largest in Europe"

Constructing the dome

Filippo Brunelleschi's design is a masterpiece of design, demonstrating a keen understanding of physics and geometry

The paintings, or frescos, of the dome's interior were completed during the 16th century

The lantern
This final feature was added several years after Brunelleschi's death and contains holy relics.

Clever construction
One theory of Brunelleschi's method is that he positioned guide ropes from the centre of the base to precisely plot the rise and inclination of the brick sections.

Decoration
From the inside, the dome is decorated with over a dozen biblical scenes, painted onto a surface area of 3,600 square metres.

Inner and outer shells
The dome is made up of two separate sections, one within the other, but both are made from plaster and bricks. The inner shell is more than two metres thick.

The mystery of Il Duomo's dome

Although the cathedral's enormous dome is considered a crowning masterpiece, it was not part of the original design. In 1418 the council of Florence ran a competition to design the grandest dome to sit atop the new cathedral, and the winning plan belonged to an engineer called Filippo Brunelleschi.

He envisioned a huge arching structure that would see Il Duomo reach an impressive 114 metres high. Not only was the plan ambitious, its achievement has baffled experts for centuries. The dome was constructed without the use of a central scaffold to support the drying bricks, which would be added layer by layer over 100 metres above the ground. Eight sections of brick join at the precipice, arching at a seemingly impossible 60-degree angle. Though many have speculated on how Brunelleschi achieved this feat of genius, unfortunately he took his secrets with him to the grave, which is located in the crypt of the cathedral.

Wooden frame
It is likely Brunelleschi used timber frames to help guide the correct angle of the dome, but these were removed afterwards.

Brick layers
The bricks supported their own weight as they dried during the build, alternating between vertical and horizontal positions in what's called a herringbone pattern.

Heavy lifting
Brunelleschi devised counterweight cranes to be positioned on top of the dome, enabling heavy building materials to be lifted.

Supporting rings
Several stages of interlocking rings made from stone and wood prevent the dome from collapsing outwards under its own weight.

Brunel's block machines

How one man steered the Royal Navy into the modern age

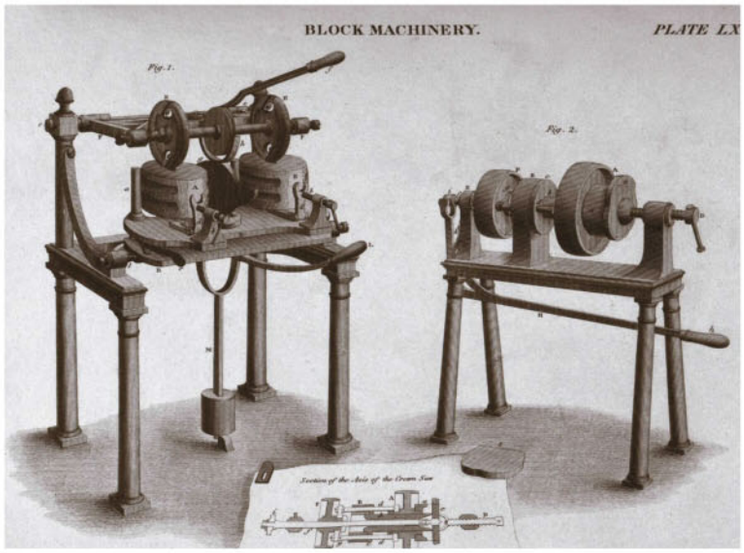
Everyone's heard of Isambard Kingdom Brunel, the man who built Britain, but did you know his father was also an extraordinary engineer? In the late 1700s the Royal Navy was struggling to expand its fleet fast enough to compete with overseas powers, and Marc Isambard Brunel came to their rescue. His patented block-making machines were the first all-metal production line and boosted efficiency in the process of making ship parts. They also enabled a precision and uniformity that was previously unheard of.

The machines were so efficient that just ten men, along with a 30-horsepower steam engine, could replicate the work of over 100. What's more, they didn't need to be skilled craftsmen to oversee the production process.

There were approximately 22 different types of machines used to complete the process, including sawing logs into blocks, drilling holes for axles and shaping the exterior. By 1805, over 40 machines were built in the Portsmouth dockyard, and by 1808 around 130,000 blocks of various sizes were produced each year. Some machines were still in operation over 150 years later. Brunel's invention kick-started the age of mass production and became the precursor to modern factories around the world.

A ship's pulley-block made by Brunel's machines

Interior of the Portsmouth Block Mills circa 1900; block making ceased production here in the mid-1960s



A drawing of some of the machinery that was installed at the dockyard, which was made by skilled tool-maker Henry Maudslay

Fore-edge painting

The tale of how books were transformed into works of art

Some centuries-old books contain more than just a story: hidden beneath their gilt edges are pieces of art that can only be revealed by bending the pages. These secret pictures are known as fore-edge paintings. The images reflect scenes described within the books themselves, and they were created by clamping the pages in a fanned position and painting miniature scenes on the margins with painstaking detail. The clamp was then released and the edges of the book were brushed with gilt to obscure the image.

This technique was developed in 17th-century England by Samuel Mearne, a bookbinder to the royal family. The trend swept the nation. Some artists even produced double fore-edge paintings, where two different images would be revealed depending on which direction you fanned the pages. Others would paint a panoramic scene along all three edges.

However, the practice actually began a century earlier when the Venetian artist Cesare Vecellio turned his pages into a canvas. Instead of concealing his masterpieces, the artist displayed his handiwork in full view for the reader. Not only did this enhance the beauty of the books, it was also easier to identify subjects on the shelf. Although the popularity of fore-edge painting has waned, there are still some specialists creating art on the edge today.

This prayer book bears a fore-edge painting, added to it in around 1930

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BRAIN DUMP

Because enquiring minds need to know...

MEET THE EXPERTS

Who's answering your questions this month?

Laura Mears

Laura studied biomedical science at King's College London and has a master's from Cambridge. She escaped the lab to pursue a career in science communication and also develops educational video games.

Alexandra Franklin-Cheung

Having earned degrees from the University of Nottingham and Imperial College London, Alex has worked at many prestigious institutions, including CERN, London's Science Museum and the Institute of Physics.

Tom Lean

Tom is a historian of science at the British Library, where he works on oral history projects. He published his first book, *Electronic Dreams: How 1980s Britain Learned To Love The Home Computer,* in 2016.

Katy Sheen

Katy studied genetics at university and is a former **How It Works** team member. She now works for a biomedical journal, where she enjoys learning about the brilliant and bizarre science of the human body.

Joanna Stass

Having been a writer and editor for a number of years, **How It Works** alumnus Jo has picked up plenty of fascinating facts. She is particularly interested in natural world wonders, innovations in technology and adorable animals.

Most meals on the ISS come precooked and sealed into packets – like microwave meals

What food do they eat on the Space Station?

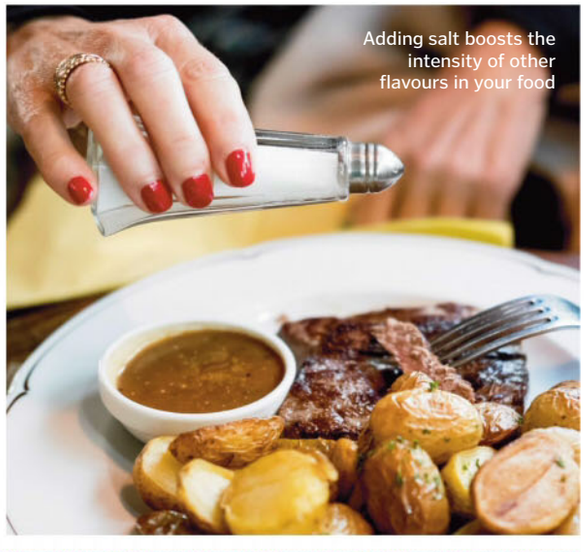
Catherine Brown

ISS crews have a varied diet of over 100 dishes, offering everything from soup, pasta and fruit to fajitas and mashed potato. However, mostly it's specially prepared for conditions on the ISS. Many meals are precooked and sealed on Earth, then warmed up and eaten from their pouches. Other foods are freeze-dried or dehydrated, so water is added before eating. Tortillas are eaten onboard instead of bread to avoid crumbs floating around in zero gravity, and salt and pepper come as liquids. Space meals have come a long way since the very first astronauts ate food paste squeezed from tubes. **TL**

How does salt improve the flavour of food?

Amber Hill

Taste receptors on the tongue respond to five basic flavours: salt, sweet, sour, bitter and umami. These flavours interact in complex ways to boost or suppress how much of each is picked up by your taste receptors. When you add a small amount of salt to sweet foods it reduces bitterness, which is perfect for a cookie or cake. When you add lots of salt to savoury foods, it decreases sweetness and boosts umami flavours, making your plate of food even more tempting. **KS**



Adding salt boosts the intensity of other flavours in your food

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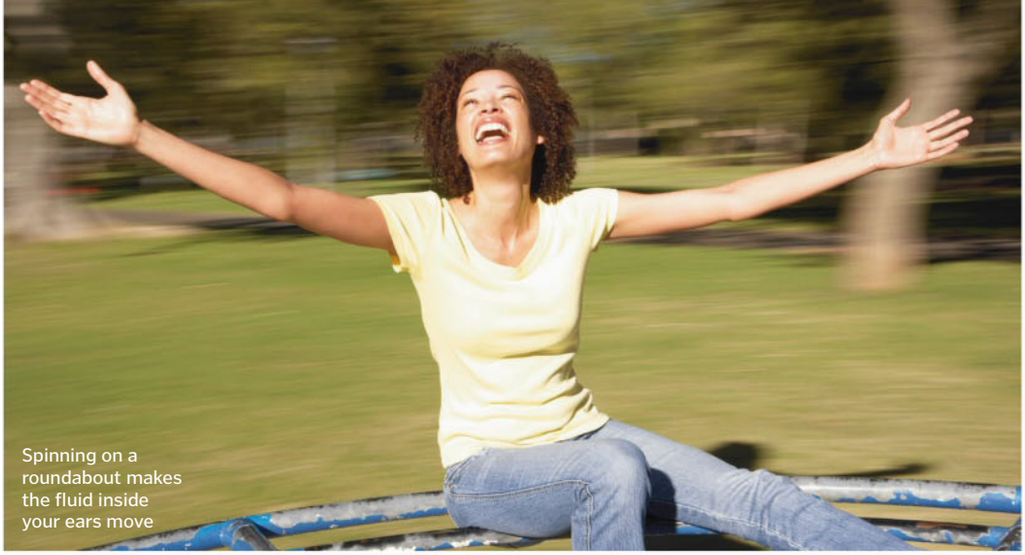
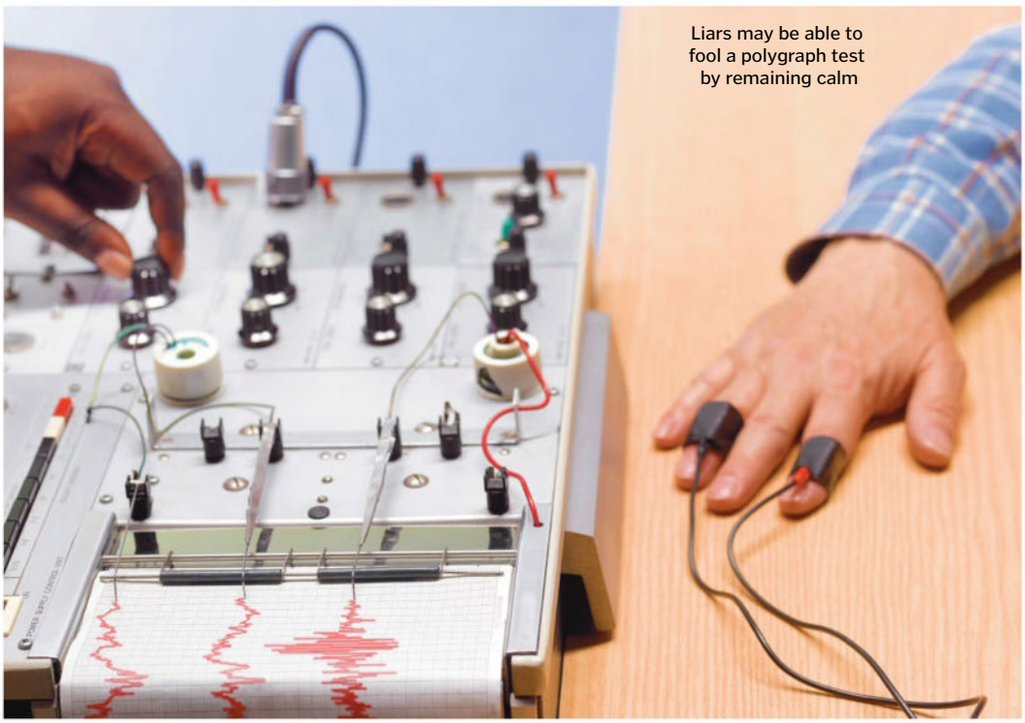


Spinning on a roundabout makes the fluid inside your ears move

Why does spinning make me dizzy?

Jamie Cahill

The inner ear contains three fluid-filled tubes called semicircular canals. They work a bit like a biological spirit level. Fluid sloshes around the canals when you move, brushing past tiny hairs. As the hairs bend, they send messages to the brain telling it which way you are tilting. When you spin, the movement of the fluid catches up with the movement of your head and the hairs relax. When you stop spinning, the fluid keeps moving and the hairs bend in the opposite direction. This makes it feel like you're spinning backwards, but your eyes tell your brain that you aren't, and that's what makes you feel dizzy. **LM**



Liars may be able to fool a polygraph test by remaining calm

How do lie detectors work?

Caroline Jackson

Lie detectors, or polygraphs, monitor the body's stress responses to try and identify if someone is lying. The subject is hooked up to several sensors to detect responses such as heart rate, blood pressure, breathing rate and sweating. They are asked some simple questions at the beginning of the test, so that their normal levels are recorded, then the real questions follow. If the person is lying, the theory is that they will feel nervous, and spikes in their stress responses will give them away. However, polygraph results are not reliable enough to use in courts of law. **KS**

What are contact lenses made of?

Alexandra Sloane

Soft contact lenses are made of hydrogel plastic, which absorbs water to keep them supple. Rigid gas-permeable contact lenses are made from silicones and fluoropolymers, which allow oxygen to pass to the cornea. **JS**

What does engine oil do?

Lucia Cruz

Engine oil lubricates the moving parts in a car engine, reducing friction and therefore energy loss. It also protects components against wear and removes dirt and contaminants. **AFC**

What are 'fatbergs'?

Chelsea Havers

A fatberg is a congealed mass of fat, wet wipes and other sanitary products that can block sewers. They can form when people pour waste oil or fat down drains and flush wet wipes down the toilet, causing solidified fat and litter to clump together. **AFC**

What's the difference between unleaded and 'premium' unleaded petrol?

Rachel Charles

Premium unleaded has a higher octane rating – it contains a higher percentage of isooctane, a hydrocarbon that helps to prevent 'engine knock', a sound caused by the mixture of air and fuel in the engine igniting too early. **JS**

BRAIN DUMP

Why do some geysers erupt so regularly?

Davood Ahmed

■ Each geyser sits atop a unique network of cavities and fractures within a rock, and it is unclear what differentiates regularly erupting ones. Geysers require a rare combination of geothermal heat, abundant groundwater and interconnected chambers inside rock where water and steam can collect. Side chambers in the rock trap pockets of steam at depth, which bubble up, heating the water above. Although the water at depth reaches 100 degrees Celsius, the weight of the water above initially prevents it from boiling. Then the surface water starts to boil, relieving the pressure and allowing the water below to boil abruptly, triggering a violent eruption. **AFC**

There are about 1,000 geysers in the world, half of which are in Yellowstone Park in the US

Why do cats scratch the furniture?

Jonathan Atkinson

■ Scratching is a normal behaviour for cats. They do it to keep their claws in good condition and as a way of communicating with other cats. When they scratch, scent glands in between the pads of their paws leave behind a unique smell that, along with the scratch marks, remind other cats that this is their territory. To stop them ruining your furniture, you can provide them with a scratch post to (hopefully) use instead. **JS**

All indoor cats should be provided with scratching facilities

What is a 'bothie'? Xavier Cole

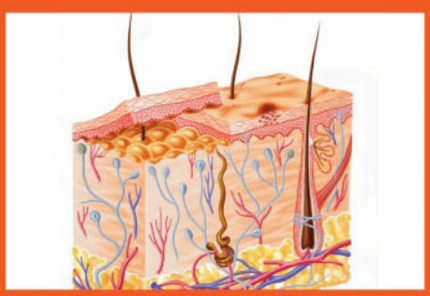
A bothie is a photo taken with the cameras on the front and back of your smartphone simultaneously, making a split-screen image of you and what you are looking at. **TL**

How come most airliners are painted white? Helen Beale

White reflects sunlight far better than darker colours do and so helps to keep the airliner cool, protecting its structure and electronics and making it easier to keep passengers at comfortable temperatures. It's also easier to spot any cracks and damage to the plane against a white background. **TL**

How fast do fingernails grow? Jen Reeve

Dr William B Bean measured his nail growth for 35 years and found that his left thumbnail grew by approximately a tenth of a millimetre each day. As he aged he noticed the growth gradually slowing down. **LM**



Why don't people get hair cancer? Ben Cairney

Cancer happens when cells can't stop making copies of themselves, dividing again and again until they form a tumour. You can't get hair cancer because the cells in hair are already dead. However, there are types of skin cancer that affect the hair follicles, where the cells are still alive. **LM**

Kevlar is used to make bulletproof vests, car tyres and cut-resistant gloves

What is Kevlar made of?

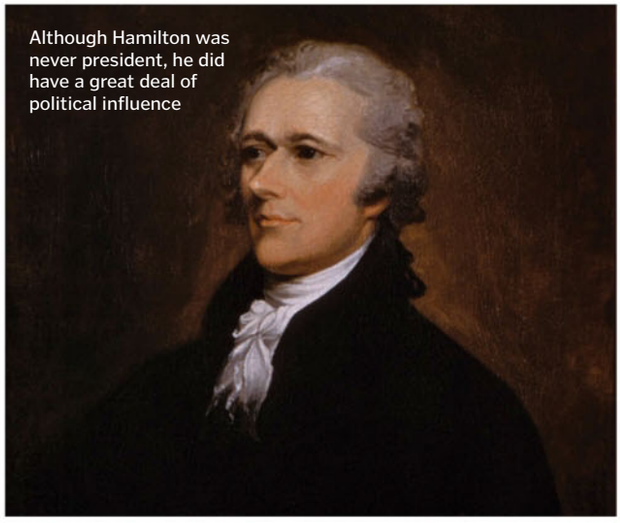
Christina Lewis

Kevlar is an aromatic polyamide, a type of plastic in which the molecules form long chains, arranged in regular, parallel lines. It is created by a condensation reaction fusing 1,4-phenylenediamine and terephthaloyl chloride. The resulting material is heated and forced through a sieve-like structure that shapes it into long, stiff fibres. These fibres are light but incredibly strong and decompose at temperatures between 427-482 degrees Celsius in air. **AFC**

Why do you 'see' patterns and lights if you rub your eyes?

Anthony Hall

The lights and colours that you see are called 'phosphenes'. They appear because pushing on your eyes affects the cells in your retina. This activates your retinal ganglion cells, which send signals from your eyes to your brain. It also affects how much blood can get through the back of the eye. When the cells don't have enough oxygen, they can misfire, making it seem like you're seeing lights. **LM**


Although Hamilton was never president, he did have a great deal of political influence

Who was Alexander Hamilton?

Sally Jenkins

Alexander Hamilton was one of the Founding Fathers of the United States of America. As well as serving in the military and becoming a successful lawyer, he was also General George Washington's assistant and later, when Washington became president, his secretary of the treasury. He championed the Constitution, the US supreme law that strengthened the federal government, and was influential in getting it ratified in 1788. He also founded the United States' first national bank, the US Mint, the US Coast Guard and the *New York Post* newspaper. He was killed in 1804 by his political rival Aaron Burr, the US vice president. **JS**

How long can submarines stay submerged?

Philip Walton

There are many types of submarine, but modern nuclear-powered subs can stay underwater longest, potentially over 100 days at a time. The nuclear reactors that power them can go for years without refueling and provide energy to process seawater into drinking water and oxygen. The real limits to endurance are how much food they can carry and how long the crew can stand being cooped up together in the submarine's cramped compartments without losing their effectiveness. **TL**

Why do carriage horses wear blinkers?

Maria Murdock

Blinkers reduce a horse's peripheral vision, keeping it focused on the path ahead. This reduces the chance of the horse getting scared or distracted, which could cause it to rear up or run off at speed. Carriage horses wear blinkers to make it safer for them to pass through crowded areas by protecting the horse's eyes from harm. **KS**

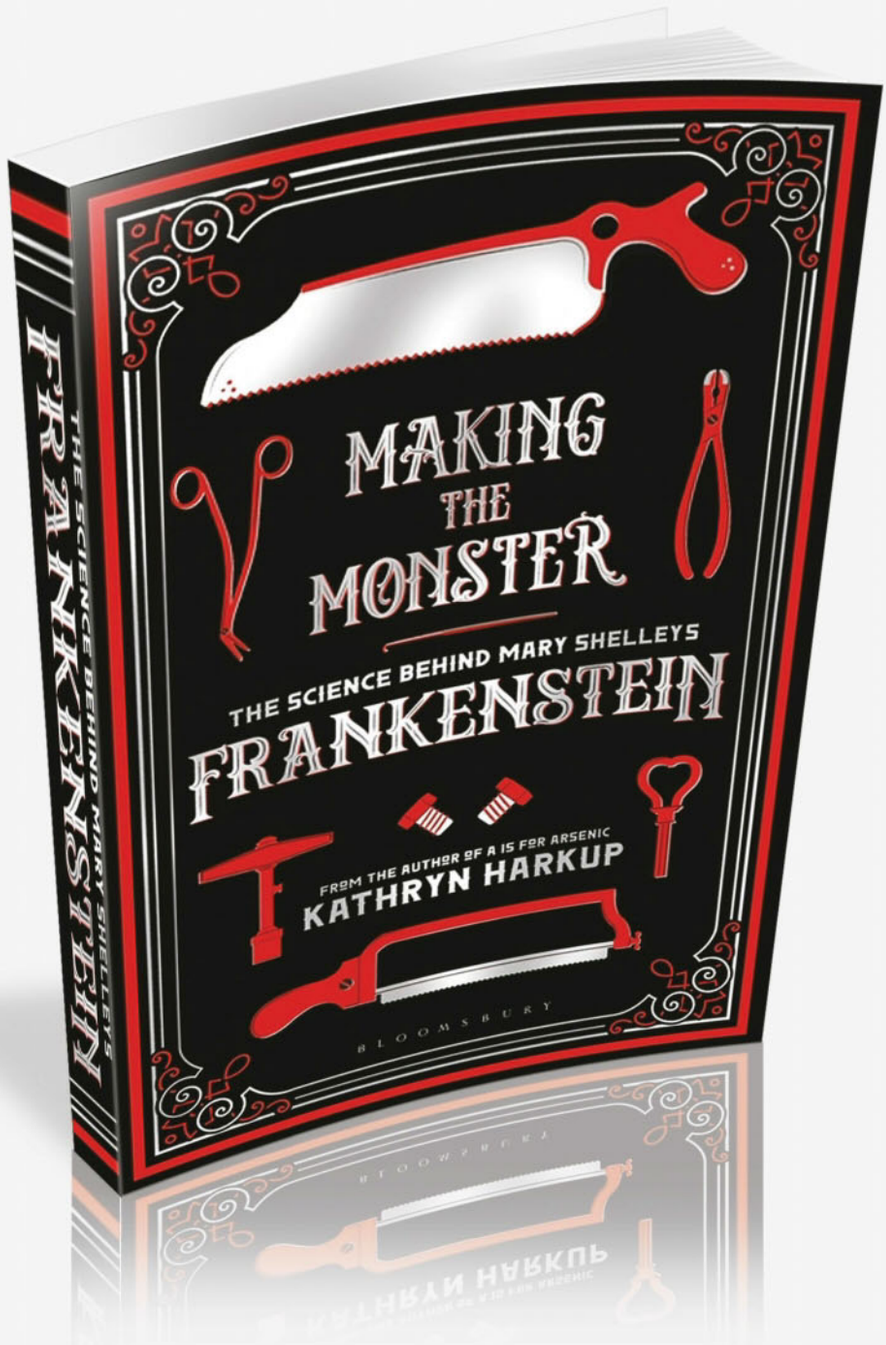
BOOK REVIEWS

The latest releases for curious minds

Making the Monster

The science behind Mary Shelley's *Frankenstein*

- Author: **Kathryn Harkup**
- Publisher: **Bloomsbury Sigma**
- Price: **£16.99 / $27**
- Release date: **Out now**



The life of Mary Shelley may surprise you. It certainly surprised us when we first read about it. The author of *Frankenstein* endured many hardships, met many incredible people and went on some truly amazing journeys during her short life, with experiences that helped shape one of the most famous – and most influential – science fiction stories of all time. Kathryn Harkup's exploration of Shelley's life and the science that she used in creating her literary masterpiece mixes biographical elements with studies of the scientific community in the late 18th and early 19th centuries to excellent effect.

Starting with a history lesson, the book aims to frame the world in which Shelley grew up. Born in 1797 into a Britain that had been defeated in the American War of Independence in 1783, the early part of Shelley's life witnessed Britain waging an almost constant war with France. However, this was also a time of enlightenment, and thanks to her successful parents, Shelley was introduced to great minds at a young age, including William Wordsworth.

Harkup bustles through Shelley's early years quickly but effectively, giving us a clear idea of why she was such a keen writer before moving on to her later life, her experience of the sciences and the discoveries that inspired her to write what would be her defining novel.

> "While biographical, the book also explores electricity and anatomy"

The book, while mostly biographical in tone, darts from topic to topic, exploring electricity, chemistry, anatomy and more. Harkup does an excellent job of keeping the tone light and engaging, including enough detail to help you understand what she is talking about without becoming dull. However, the real victory is in explaining how the science that Shelley included in her famous book was wrong and discussing the challenges we as readers would face if we attempted to complete the experiments that Victor Frankenstein had no trouble with.

The result is an interesting and well-paced collection of biographical and scientific essays centred on Shelley. While fans of the author won't find any revelatory new details here, they will find this book to be an entertaining trip, one that combines well-written scientific analysis with the extraordinary life of one of Britain's first sci-fi writers.

★★★★☆

Graphene

This material will change your life… maybe

- Author: **Les Johnson, Joseph E Meany**
- Publisher: **Prometheus Books**
- Price: **£16.99 / $19**
- Release date: **Out now**

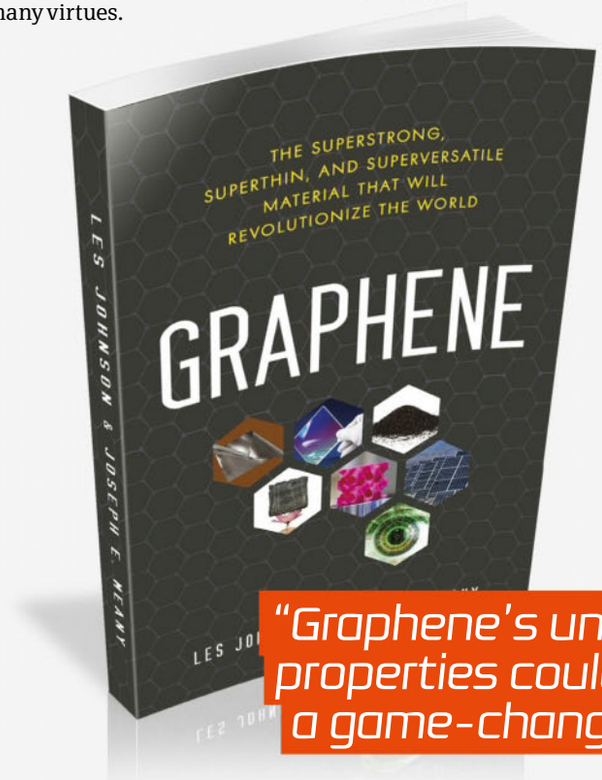
This book's rather lengthy subheading is *The Superstrong, Superthin and Superversatile Material That Will Revolutionize the World*. Hyperbole has always been a bookseller's best friend, but in the case of the aforementioned title, it might one day come to be viewed as having undersold things somewhat.

As you will discover, graphene's unique properties could well be a game-changer in years to come. Lightweight, thin and flexible yet dense and superstrong (tests have already proven its worth for making effective body armour), it has the potential to revolutionise surgery, technology and electronics, among numerous other fields. This may all seem too good to be true, but authors Les Johnson and Joseph E Meany PhD are well placed to expound its many virtues.

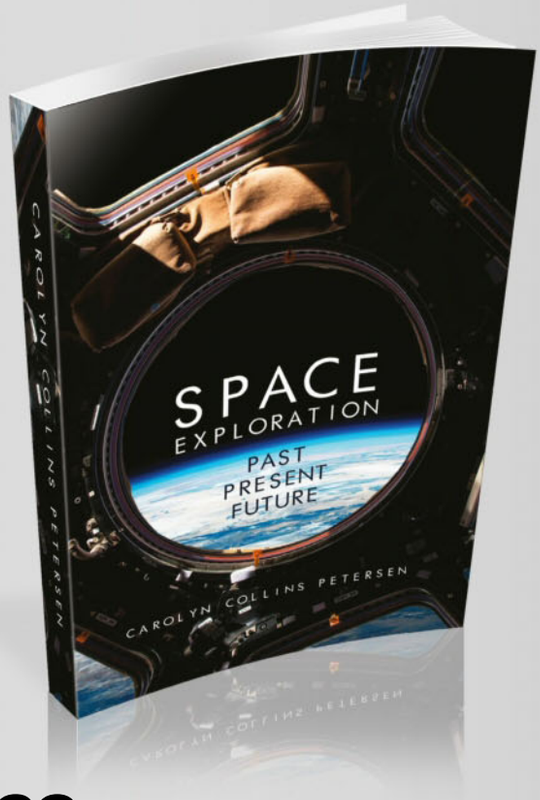
And expound them they do, detailing its potentially myriad of uses while simultaneously explaining the origins of the material, why its potential is so much higher than other so-called 'carbon miracle materials', the current state of the race to harness it and exactly why it's taking as long as it is to do so. There's a clear and genuine love for the subject matter here, making this a far easier and more enlightening read than it could have been.

Of course, books with such eye-catching claims come with caveats, with this one's being that we're still some way off unleashing graphene's full potential. Even so, this book provides an exciting glimpse of something that is potentially life-changing.

★★★★☆



"Graphene's unique properties could be a game-changer"



Space Exploration: Past, Present, Future

The final frontier revisited

- Author: **Carolyn Collins Petersen**
- Publisher: **Amberley**
- Price: **£20 / $26.95**
- Release date: **Out now (UK) / 1 April 2018 (US)**

Space exploration is one topic that continues to evoke excitement and amazement in equal measure, especially considering that in the grand scheme of things, our understanding of it is still very much in its infancy, in spite of how far we've come.

In this context, *Space Exploration* effectively functions as a marker of where exactly we are at this point in time, looking back at how we first made the journey outside the confines of Earth before examining the subsequent impact this has had on both the world and on our lives. It then moves on to the current private enterprise-driven quests to make travel to Mars possible and what's next when – not if – we finally make it there.

When you consider how much work needs to be done before manned expeditions to the Red Planet become viable, it's easy to take a pessimistic view of our spacefaring future. Here, however, the outlook is one of optimism. Yes, there is still plenty to be done, but we have also come a long way, and this fact is underlined throughout this book. The issues aren't ignored, but you'll read far more about the technologies that may be used and the current attempts by the likes of SpaceX and Mars One to make colonisation of Mars a reality.

The fact that the book closes by detailing some of the more evocative fictional depictions of the Red Planet highlights that we're still very much filling in the gaps when it comes to working out our next step. But regardless of this, you'll find strong grounds for optimism in this book.

★★★★☆

BRAIN GYM

GIVE YOUR BRAIN A PUZZLE WORKOUT

Wordsearch

F	H	B	E	S	P	A	C	E	J	U	N	K	L	S
O	Y	A	J	M	R	V	U	P	L	J	F	Z	A	U
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S	F	A	R	A	D	A	Y	W	H	B	R	H	V	X

FIND THE FOLLOWING WORDS...

AVIANS
BAKING
BATS
FARADAY
FOREEDGE
HYDRAULIC
HYPOTHERMIA
IPHONEX
LASER
MILITARY
NANJING
PARASITE
PLACEBO
QUEENBEE
SOLARPOWER
SPACEJUNK
SURFBOARD
WEAPONS

Quickfire questions

Q1 One micrometre is...

- $1x10^{-6}m$
- $1x10^{-8}m$
- $10x10^{-6}m$
- $1x10^{-10}m$

Q2 The US Prohibition Movement (1920–33) banned what?

- Cars
- Protests
- Alcohol
- Guns

Q3 In mathematics, what is the definition of an imaginary number?

- i = 3.141...
- i = √-1
- i = n!
- There is no such thing

Q4 Cocoa beans come from which plant?

- Cadburium cacao
- Camellia sinensis
- The Yumyum tree
- Theobroma cacao

Spot the difference

See if you can find all six changes we've made to the image on the right

Sudoku

Complete the grid so that each row, column and 3x3 box contains the numbers 1 to 9. See if you can beat the team!

EASY

2			4			9	3	6
				3	9	5	2	8
8	3			5				7
							5	3
	8	4				7	9	
9	1				8	2		4
6			3	2	7	1		
	4	5		9		3	7	2
3	7	2	1					

DIFFICULT

1	7	3		8				
		9				7		
			7	6		1		
5		1	6			2		
			3		4	5		
4		6	9		2		7	
		5					3	7
			5			6	4	
6	4			2	3			5

What is it?

A .....

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Jackie Snowden, Editor

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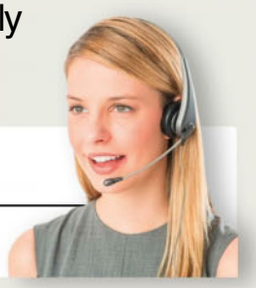

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Get in touch

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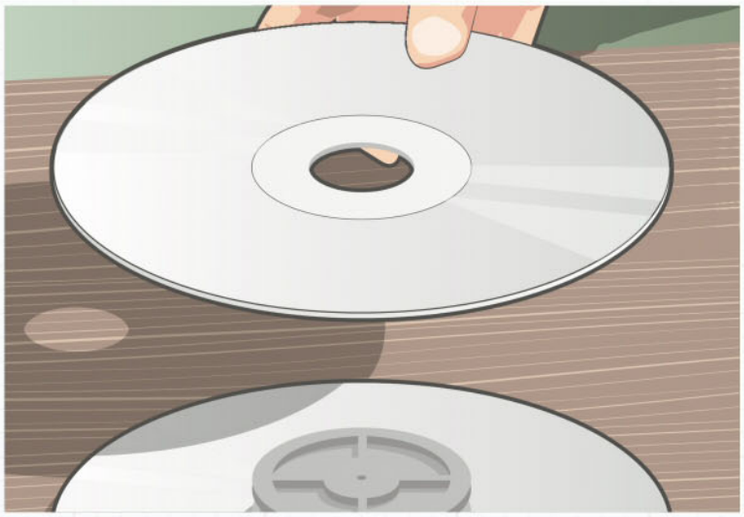
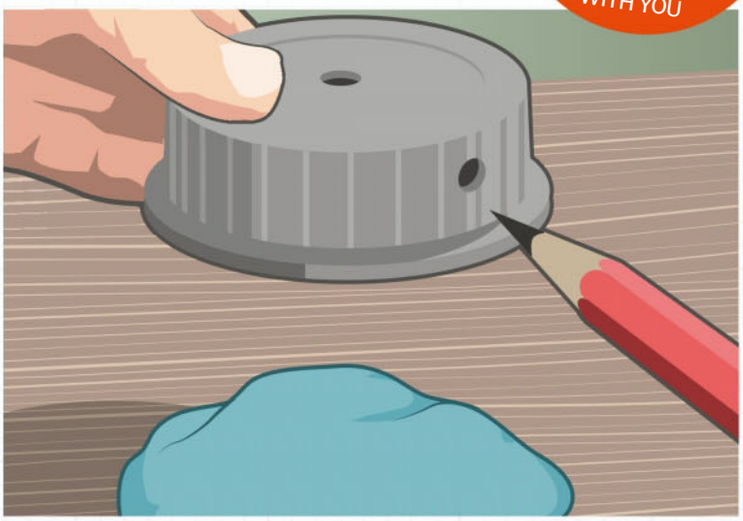
Make a teddy bear zip wire

DON'T DO IT ALONE
IF YOU'RE UNDER 18, MAKE SURE YOU HAVE AN ADULT WITH YOU

Send your teddy zooming across the room with this simple ropeslide!



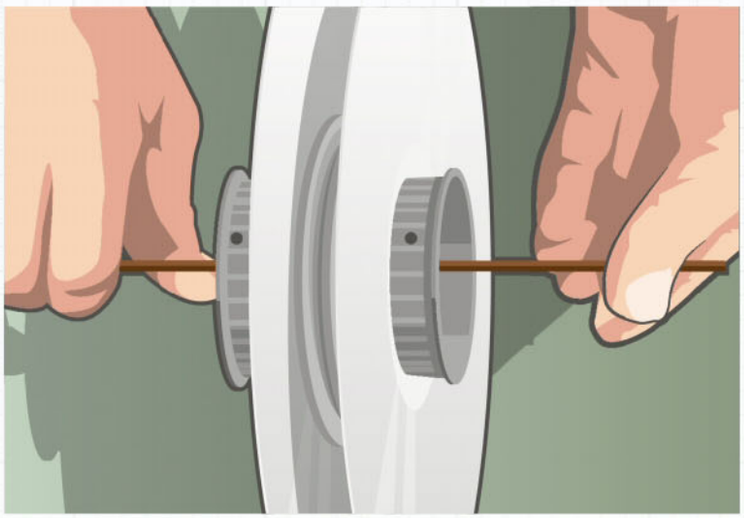


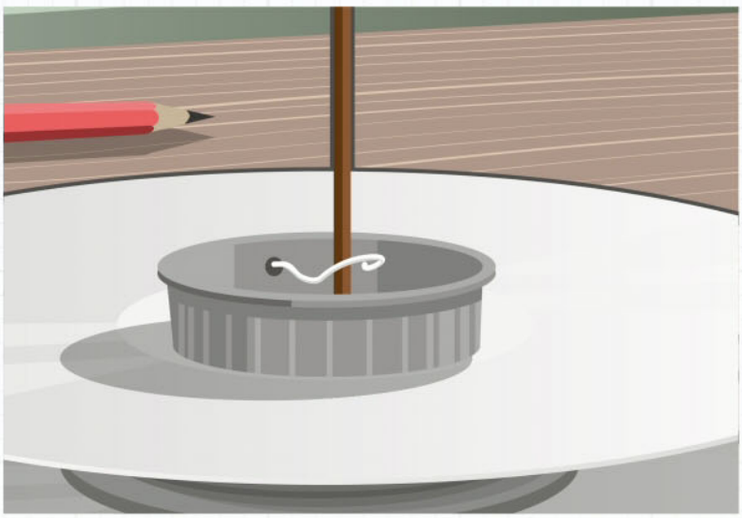
1 Make the wheel

Using sandpaper, roughen up the central parts of two CDs, then attach them to a plastic pulley with glue. This pulley needs to have a V-shaped ridge in the middle so that the string of the zip wire runs through it smoothly – make sure not to get glue in the V-shaped ridge as you attach it to the CDs! Also ensure that the centre of the pulley is lined up with the centre of the two discs.

2 Skewer it!

Now you can place a wooden skewer through the centre of the pulley and CDs that you've put together. Next, take two milk bottle caps and carefully make a hole in the centre of each one. Be careful not to make them too big, as the caps need to fit tightly onto the skewer. You will also need to make a hole of the same size in the side of the bottle tops.



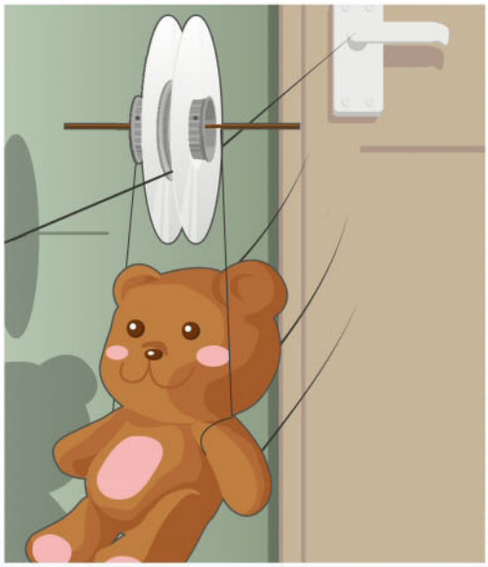


3 Put it together

You now need to slide the two bottle tops onto the skewer as well, with one on each side. Make sure that if you hold the lid, the rest of the pulley rotates freely – if it doesn't, try moving the two lids away from the CDs very slightly. Line up the two holes that you previously made in the sides of the bottle tops so that they are both pointing in the same direction.

4 Attach your pilot

Now, using a pair of scissors cut off the long parts of the skewer that are sticking out of each side of your pulley, leaving a centimetre or so on each side. Then thread a piece of string through the hole in the side of the bottle top and tie it to your teddy's arm. Do the same on the other side. Your pilot is ready to go!



5 Test gravity

It's time for launch! Tie a long piece of string across a room so that one end is higher than the other – try tying it to a door handle at one end, feeding it through the pulley and tying it to a chair at the other. Then let your teddy go! The zip wire will speed along as the pulley lets the system roll – if the friction was higher it wouldn't work.

"The zip wire will speed along as the pulley lets the system roll"

In summary...
Gravity causes the teddy to move down the wire, and the rolling pulley reduces the friction to allow it to move. Try pushing the bottle caps close to the CD – does the pulley system still work? You can also experiment with different slopes or loosen the string slightly so the teddy slows down at the end of the line instead of crashing.

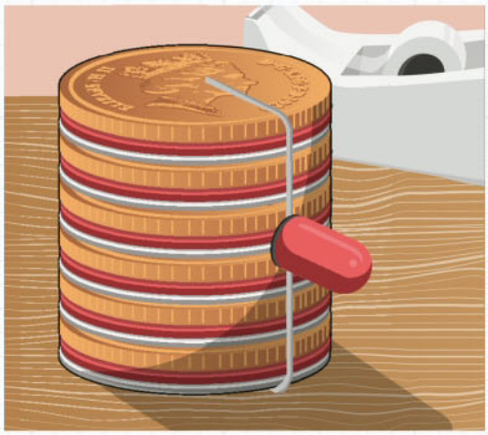
NEXT ISSUE
MAKE YOUR OWN CARTESIAN DIVER
BUILD A PERISCOPE

Build a coin battery

Generate electricity using just some coins, washers and vinegar

1 Prepare your materials

To make a battery, you'll need six copper coins (ideally 2p pieces), six zinc-coated M6 or M8 washers, a piece of felt, a standard LED and a little vinegar. Draw around one of the coins on the felt six times and cut out these discs, then soak them in the vinegar. This acid will react with the zinc and the copper to start a chemical reaction that should generate electricity, and we'll be able to see it thanks to the LED.



2 Build your stack

Now you need to put the layers together. First, place a washer down, then a piece of felt, and top it with a coin. Repeat this five more times until you have a small stack. Take the LED and bend the legs at right angles so that they fit tightly around the stack. Does it light up? Current only flows through LEDs in one direction, so if it is not lighting up try swapping which end the legs of the LED are touching.

3 Test and tweak

To secure your stack and to stop the LED falling off, use sticky tape to attach it all together. How long does the LED stay lit for? When the light eventually goes out, take the stack apart and take a look inside at the washers and coins – you should see that they will have discoloured as the chemical reaction took place. Try using larger stacks of coins, washers and felt to see if this affects how bright the LED glows, or for how long.

In summary...
When the two metals react with the acidic vinegar, a negative electrical charge builds up on the zinc washer and a positive electrical charge builds up on the coin. This charge is strengthened by more coins and washers, and the LED completes the circuit.

INBOX
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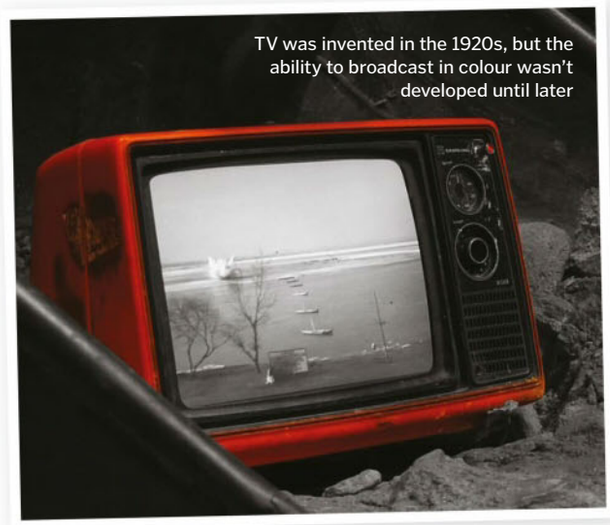
AMAZING PRIZE FOR LETTER OF THE MONTH!
VACATION GUIDE TO THE SOLAR SYSTEM
Discover the wonders of our neighbouring planets and moons in this brilliant travel guide packed with real-world science

Letter of the Month

Monochrome media

Dear **HIW**,
I'm a big fan of your magazine. Thanks for all the amazing facts and info! I was wondering about black and white TV. What limited people from broadcasting in colour back when they only had black and white?
Thanks,
Edward Kammermann, aged 12

Hi Edward, and thank you for your email. The invention of television in the 1920s allowed us to send moving images across the world for the first time. TV screens at the time would have been coated with a white-emitting phosphor that in response to an electron beam 'painted' an image on screen by moving across the phosphor. By the 1960s colour TVs had started broadcasting. A colour screen relies on three types of phosphors emitting red, green and blue light arranged as dots or stripes. They can be illuminated together using three electron beams. The jump from black and white to colour TV was due to the development of a more complex version of the same technology, but it took a little while for it to roll out.


TV was invented in the 1920s, but the ability to broadcast in colour wasn't developed until later


The K-T extinction wiped out around three-quarters of the species on Earth

The K-T extinction event

Hello **HIW**,
I have a question to ask. Can you please tell me how did the megalodon and pterodactyl survive the deadly asteroid when it killed all the other dinosaurs?
Thank you
From Cruz, aged 7

Thanks for your question Cruz. The deadly asteroid that killed the dinosaurs wiped out almost all of the animals on Earth, but you are right, the megalodon survived the K-T extinction. In fact, the megalodon went on to live for many more millions of years, eventually becoming too large and going extinct when it ran out of prey. Pterodactyls didn't survive this extinction event, but some flying animals did because they were able to escape the heat when there was a drastic rise in temperatures following the impact. Thanks for writing to us Cruz, it was great to hear from you.

Seeing through time

Dear **HIW**,
I've been reading your magazines for a while now, and after reading a recent article about black holes I've become curious about how telescopes can see back in time. I'd be really grateful if you could help me answer this question! Thank you!
Henry Shadbolt, aged 12

Great question Henry! Technically, all telescopes look into the past. The speed of light is incredibly fast (nearly 300 million metres per second in a vacuum), but it cannot travel from one place to another instantly. For example, the light from our Sun takes around eight minutes to reach Earth. When we look at the stars, the distances between them are so huge that it takes a long time for their light to reach us. We often describe the distances to stars as being a certain number of 'lightyears' away, meaning it takes light that many years to reach Earth. If a star is four lightyears away, for example, the bright light we see through a telescope is four years old and therefore we are witnessing the star as it appeared four years ago.


The Sun's closet neighbouring stars are Alpha Centauri A and B at around 4.3 lightyears

© Pixabay/Getty

What's happening on... social media?

"Dr. King was 26 when the Montgomery bus boycott began. He started small, rallying others who believed their efforts mattered, pressing on through challenges and doubts to change our world for the better. A permanent inspiration for the rest of us to keep pushing towards justice."
@BarackObama

"The Boring Company flamethrower guaranteed to liven up any party!"
@elonmusk

"There'll be some great views of the #SuperBlueBloodMoon from up there today!"
@astro_timpeake

"Do you think it's safe to assume that any twitter user with more than about 4 numbers after their name is a bot?"
@ProfBrianCox

"Occasionally I have a momentary lack of confidence with a small DIY project and then I remember that I was responsible for a 20 million dollar telescope in Antarctica for 10.5 months and I am like yea nbd I can probably give it a shot at least"
@corbett

HOW IT WORKS

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Issue 110 on sale 22 March 2018

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+

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The science of extreme sports

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■ FLOATING CITIES ■ THE GREAT EXHIBITION OF 1851 ■ VLBI ■ WW1 POST ■ SENSING TIME ■ HIMALAYAN WILDLIFE ■ MAKING PAPER ■ iMAC PRO

FAST FACTS

Amazing trivia to blow your mind

BRUNEL'S BLOCK-MAKING MACHINES ENABLED TEN UNSKILLED WORKERS TO DO THE WORK OF AROUND 110 SKILLED CRAFTSMEN

1 MILLION

THE ESTIMATED NUMBER OF DEATHS CAUSED BY PARASITIC DISEASES EACH YEAR

150 MILLION

THE NUMBER OF YEARS AGO THAT BIRDS FIRST STARTED TO EVOLVE

11,000KWh

THE AMOUNT OF SOLAR ENERGY THE SOLAR IMPULSE 2 GENERATED FLYING AROUND THE WORLD

THE STAR UY SCUTI IS THOUGHT TO BE AROUND

1,700

TIMES WIDER THAN THE SUN

4 YEARS

THE TIME IT TOOK MICHELANGELO TO PAINT THE SISTINE CHAPEL'S CEILING

86 TONS

OF MICROPLASTICS FROM FACIAL EXFOLIANT PRODUCTS ARE RELEASED INTO THE ENVIRONMENT EVERY YEAR

BEES FLY UP TO AROUND

88,500KM

TO PRODUCE JUST 450 GRAMS OF HONEY

IN ITALY, THE *SNAP! CRACKLE! POP!* MASCOTS OF KELLOGG'S RICE KRISPIES ARE CALLED *PIF! PAF! POF!*

THERE ARE MILLIONS OF PIECES OF SPACE JUNK THAT ARE TOO SMALL TO TRACK

12,000–14,000 EARTHQUAKES OCCUR EVERY YEAR GLOBALLY

IN JUST

1 HOUR

ENOUGH SUNLIGHT REACHES EARTH TO MEET GLOBAL ENERGY DEMAND FOR AN ENTIRE YEAR

38 THE NUMBER OF KNOWN SPECIES OF WILD CAT

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IMAGE EDITOR

ALL-IN-ONE

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